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Chemical Vapor Deposition of Amorphous Semiconductor Films

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ABSTRACT

Intrinsic and phosphorus doped n-type amorphous silicon films have been deposited by LPCVD from disilane in a laminar flow tubular reactor. These films have been analyzed where appropriate using SIMS, ESR measurements, optical absorption and conductivity in the light and dark.

CVD deposited n+ i layers were used to make platinum Schottky barrier devices and hybrid cells utilizing glow discharge deposited boron doped p-type layers in both the ITO/nip/Mo and ITO/pin/Mo configurations.

The best P+ Schottky devices had open circuit voltages (V_{oc}) around 0.5 V and external short circuit current densities (J_{sc}) around 2.8 ma/cm^2(at 87.5 mw/cm^2, ELH). Schottky devices were not used for process optimization primarily due to uncontrolled variations in Pt depositions.

The highest efficiency hybrid cells with the ITO/ni(CVD)/p(GD)/Mo structure was approximately 1.5% (V_{oc}= 0.48V, J_{sc} = 6.7 ma/cm^2, FF= 0.36 at 87.5 mw/cm^2 ELH). The highest efficiencies were obtained with thin i layers, typically around 2000 Å. These cells showed strong enhancement of the collection efficiency with reverse voltage bias most likely due to low collection lengths, $L_c=\mu\tau E$.

The cells made in the ITO/p(GD)/in(CVD)/Mo configuration were characterized by higher V_{oc} and FF, comparable currents, and very little crossover between light and dark I-V curves compared to those with p+ deposited first. The highest efficiency for this structure was 4.0% on cell CVD 300.72-3(V_{oc}=.725V, J_{sc}=10.0 ma/cm^2, FF= .48 at 87.5 mw/cm^2 ELH). This device was 0.072 cm^2 with a well defined area (by photolithography) confirmed by laser scan and optical microscope.

Development of the chemical model describing the gas phase reactions and film growth continued. The model quantitatively describes the effluent composition (SiH_4 thorugh Si_4H_{10})when the measured growth rate is input to the model. The growth rate is well correlated with the concentration of higher silanes (heavier than Si_4H_{10}) at fixed temperature. Kinetic rate expressions and constants for growth from these higher silanes are being determined for a wide range of reaction conditions.

INTRODUCTION

Chemical vapor deposition (CVD) of amorphous silicon hydrogen films from higher order silanes is of interest as an alternative to glow discharge (GD) deposition. In contrast to GD, the reactive species in CVD are generated thermally. Among the potential advantages of CVD are absence of ion bombardment, control of impurities, uniformity, efficient utilization of raw materials and high deposition rates.

The objective of this research program is to continue studies of the low pressure chemical vapor deposition (LPCVD) of amorphous silicon (a-Si:H) from disilane by optimizing the deposition parameters to achieve high quality intrinsic films. The technical approach is based on the growth of intrinsic amorphous silicon films in a low pressure (2 to 50 torr) CVD system using a horizontal laminar flow tubular reactor.

The quality of the intrinsic amorphous material is evaluated by fabricating and analyzing diagnostic solar cells. The short circuit current density is of primary importance.

Initially, Pt Schottky barrier devices were used to identify first order problems. Presently, hybrid devices using CVD n-type and intrinsic layers with GD p-type layers are used to evaluate CVD i-layers and to optimize cell performance. Eventually, all CVD deposited devices will be studied.

As needed, the optimization of the material makes use of measurements such as optical absorption, hydrogen content, electron spin resonance, photoconductivity, and minority carrier lifetime. A chemical engineering model describing the LPCVD process is being developed to guide the material optimization, including the effects of substrate temperature, growth rate, gas velocity, and gas composition. The inlet and outlet gas compositions are measured using an on-line gas chromatograph to verify the behavior predicted by the model. A distinguishing feature of this work is the integration of film properties and device performance with the reactor analysis. The present program comprises three tasks:

(1) material preparation and analysis;

(2) device fabrication and analysis; and

(3) LPCVD kinetics and reactor analysis.

In this report, progress under each of these tasks is described.

LPCVD SYSTEM

The modular LPCVD system was designed and major equipment pieces purchased under SERI subcontract No. XG-0-9195-1. A schematic with the tubular reactor is shown in Figure 1. The reactor was previously described in QR-3 (SERI subcontract XB-2-02084-1). No substantial modifications have been made under the new contract.

As previously reported, the film growth rate depends on the substrate temperature, gas pressure and volumetric flowrate (inversely proportional to gas holding time). The behavior of the reactor as regards growth rate for substrate temperatures of 380° - 480°C, gas pressure from 2 to 36 torr and gas holding times from 3 to 48 seconds has been described in previous reports (QR3 and QR4 of subcontract No. XB-2-02084-1).

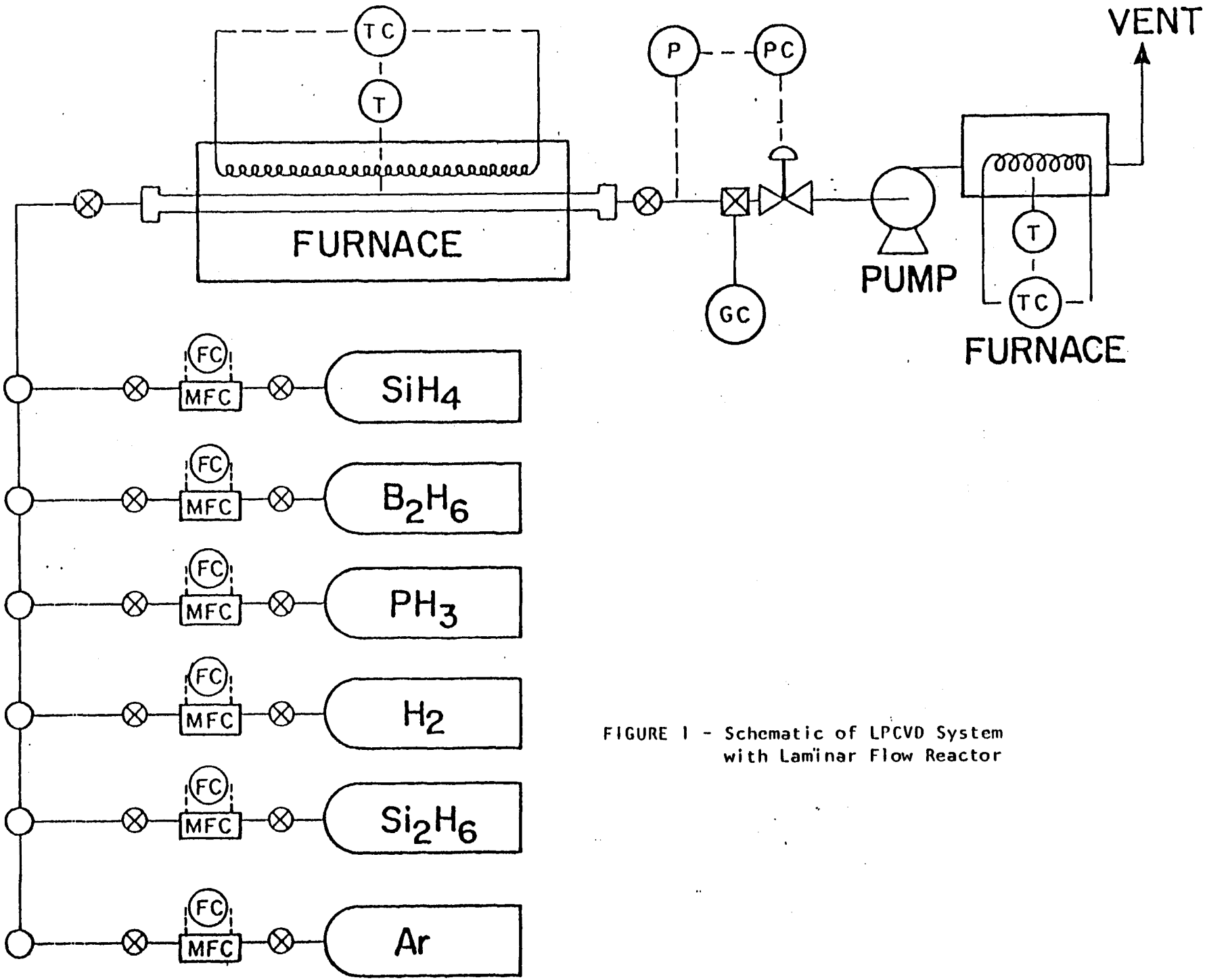


FIGURE 1 - Schematic of LPCVD System with Laminar Flow Reactor

MATERIAL PREPARATION AND ANALYSIS

During the period May 1, 1983 through October 31, 1983 one hundred thirty (130) depositions were carried out in the CVD reactor of which 90 were n-i or i-n structures for device fabrication. The remaining 40 depositions were used to provide samples for materials analysis and growth rate data for confirmation of the chemical model.

Material properties including dark and light conductivity, $\sigma_d(T)$, $\alpha(h\nu)$, and infrared absorption were measured in i layers and n layers where appropriate to survey deposition conditions. These results were described in detail in earlier reports (XB-2-02084-1). Typical values are summarized in Table 1. Table 2 (from QR3,XB-2-02084-1) qualitatively summarizes the presence of Si-H bonding as detected by IR for different substrate temperatures and growth rates.

Disilane Quality

A typical gas chromatogram of the as received disilane with the various silanes peaks identified is shown in Figure 2. The two small peaks eluting before the silane are believed to be hydrogen/argon or an artifact of the gas sampling system as they are also present in siginificant quantities (~.05%) on chromatograms of Scientific Gas Product's Epitaxial Grade Silane used routinely for calibration of the GC. The small peaks just before the disilane and trisilane peaks are believed to be impurities, present at levels around 0.01%. Up to ten to twelve such peaks have been observed in some samples of the MgSi produced disilane. No peaks at these elution times are seen in the silane calibration gas.

A newer grade of disilane marketed by Airco for Chronar Corp. has recently been obtained. An improvement in impurity content as detected by GC is apparent. Other than the same small peaks just before silane, only one 'impurity' peak has been observed, eluting just after silane. None of the impurity peaks in either grade of disilane have been identified.

SIMS Analysis

Two intrinsic films representative of state of the art material as of June 1983 were sent to RCA Laboratories for SIMS analysis. These and several more recent samples were also sent to SERI for SIMS analysis. The intrinsic films included in these samples included depositions at substrate temperatures ranging from 400°C to 430°C and growth rates from 0.7 to 4.5 Å/s. The results of these tests as regards H,C,O, and N content are summarized in Table 3 which also shows substrate temperatures and deposition rate. Sample 211CD tested at SERI and RCA was used as a standard for H,C,O and N in the other SERI tested samples. The intrinsic film of sample 211 C.D was deposited on Mo/7059 glass following a 2 hour argon purge. The other intrinsic films were grown on 100 Å of CVD deposited phosphorus doped a-Si with a 30 minute low pressure purge between layers. RCA did not test for phosphorus. SERI did not see phosphorus in the intrinsic layer at a level of approximately 10^{18}/cc. Further tests for dopant dragout will be conducted. All the samples regardless of growth rate

Table 1

MATERIALS PROPERTIES: CVD DEPOSITED FILMS

Intrinsic Films		
σ_d at 298°C	:	$0.5\text{-}5 \times 10^{-10}$ $(\Omega\text{-cm})^{-1}$
σ_p at AM1	:	$1\text{-}5 \times 10^{-6}$ $(\Omega\text{-cm})^{-1}$
E_a from σ_d (T)	:	0.7 ev
Eg_{opt}	:	1.5 - 1.6 ev
Phosphorus Doped Films		
σ_d at 298°C	:	$0.3 - 1.0 \times 10^{-3}$ $(\Omega\text{-cm})^{-1}$
E_a from σ_d (T)	:	0.25 - 0.28 ev

TABLE 2

Summary of Infrared Transmission Spectra

CVD No	Substrate Temp (°C)	Film Thickness (Microns)	Film Growth Rate Å/s	Presence of Absorption Band (+ indicates absorption observe 630 cm^{-1}	880 cm^{-1}	2000 cm^{-1}	2100 cm^{-1}
76	425	1.2	3.3	+	+	+	+
91	425	1.5	4.2	+	+	+	+
92	425	1.7	4.8	+	+	+	+
90	425	2.1	6.0	+	+	+	+
75	435	1.4	3.9	+	+	+	+
73	435	4.2	7.9	+	+	+	+
72	435	5.9	11.0	+	+	+	+
46	445	1.4	1.2	+	0	+	0
57	445	2.9	8	+	+	+	+
31	455	0.3	0.9	0	0	0	0
34	455	0.5	1.5	0	0	0	0
42	455	1.6	1.5	+	0	+	0
51	455	3.0	4.1	+	0	+	0
54	455	3.7	10.4	+	+	+	+
55	455	4.9	13.7	+	+	+	+
32	463	0.5	1.5	0	0	0	0
33	472	1.1	3.0	0	0	0	0

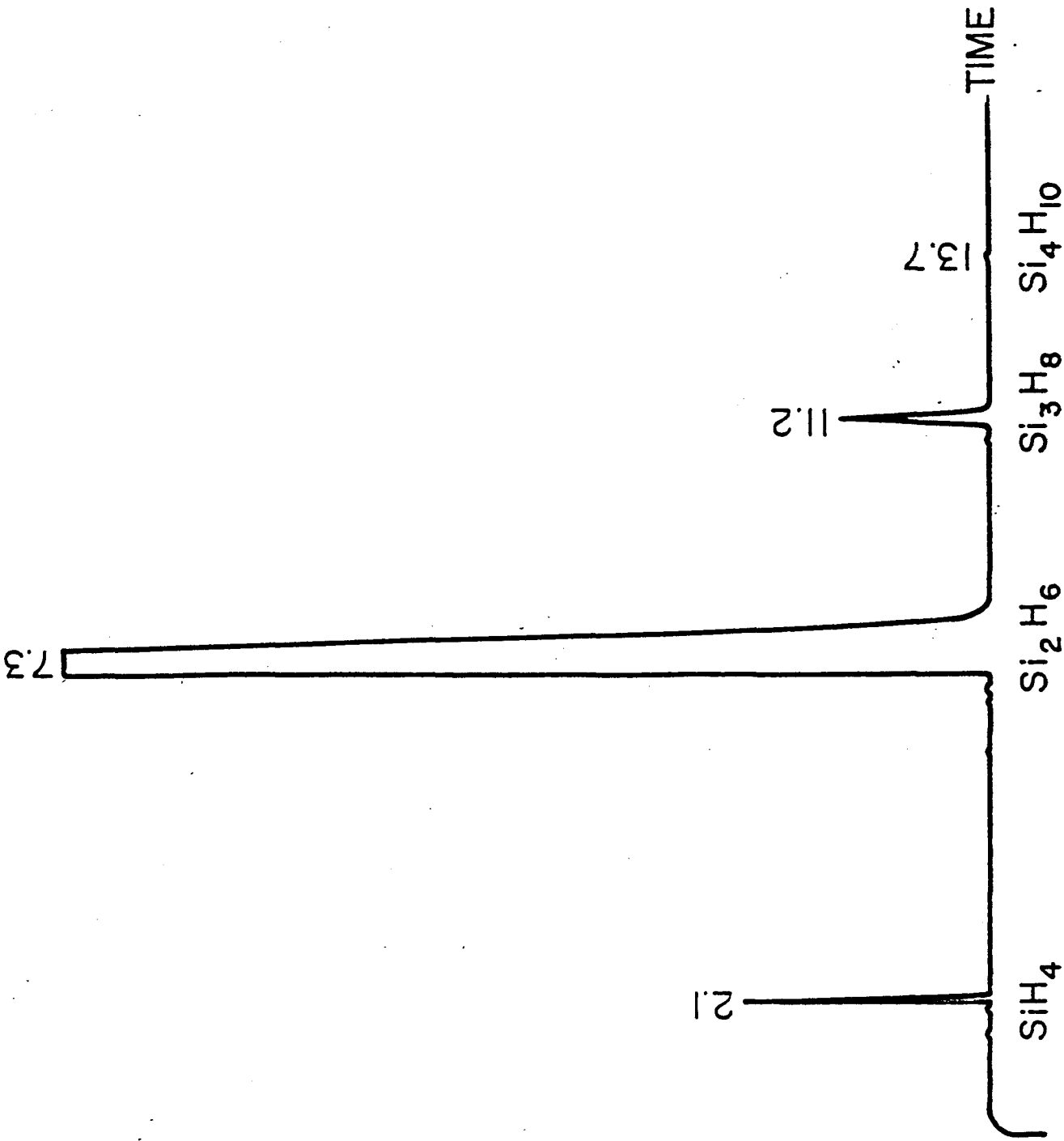


Figure 2 - Chromatogram of as Received Disilane Produced from MgSi.

Table 3

Summary of SIMS Analysis: SERI and RCA

ubstrate No.	211CD	186CD	186CD	269.72	289.72	288.42	288.72
ested by	SERI RCA	RCA	SERI	SERI	SERI	SERI	SERI
ubstrate Temp(°C)	430	430	430	420	420	400	400
ilm Growth Rate (Å/s)	3.5	4.5	4.5	3.5	2.5	0.2	0.7
npurity Conc. (cm^{-3})							
H	$4x10^{21}$	$4x10^{21}$	$5x10^{21}$	$2-3x10^{21}$	$4x10^{21}$	$4x10^{21}$	$6x10^{21}$
O	$1x10^{19}$	$1x10^{19}$	$1-2x10^{19}$	$5x10^{18}$	$7x10^{18}$	$1x10^{19}$	$7-9x10^{18}$
C	$3.5x10^{19}$	$4x10^{19}$	$3x10^{19}$	$3-4x10^{19}$	$3x10^{19}$	$3x10^{19}$	$3x10^{19}$
N	$4.3x10^{17}$	$5x10^{17}$	$5x10^{17}$	$5x10^{17}$	$4x10^{17}$	$3x10^{17}$	$3-4x10^{17}$

or substrate temperature show comparable impurity levels including less than 200 ppm oxygen and approximately 8 to 10% hydrogen. Carbon content is somewhat high compared to glow discharge material yielding high efficiency cells. Impurities in the disilane produced by the MgSi process may be contributing to this higher carbon impurity level.

ESR Measurements

Electron spin resonance measurements were made on several samples by Dr. William Carlos at NRL. Preliminary measurements of the spin densities (at g=2.0055) showed approximately 10^{17}/cc through the bulk of the CVD film and approximately 3×10^{17} at the surface. The difference between bulk and surface concentration was detected by etching the surface layer (~1000Å) of the 2 to 4 μm thick samples.

Photoluminescence

CVD samples have been prepared for photoluminescence measurements by Jack Merski of 3M. Results will be reported when received.

NOTES

DEVICE FABRICATION AND ANALYSIS

Schottky Barrier Devices

Schottky barrier diagnostic devices (Pt/i/n/Mo/7059 glass) were fabricated for preliminary device studies. The n+ and i layers were deposited by CVD. The n+ layer was typically 500Å thick while the i layer thickness was varied from 1500Å to 5000Å. The Pt window/top contact was deposited on the n+/i structure by electron-beam evaporation through 3mm diameter aperture masks yielding a nominal device area of .072 cm^2. The Pt was typically 60 to 70 Å thick with a sheet resistance less than 100Ω/□, and between 30 and 35% transmission at all wavelengths between 400 and 1200 nm. Table 4 summarizes the Schottky barrier cell results (Isc and Voc) for a variety of intrinsic layer deposition conditions. These data (CVD's 175, 176 and 178: CVD's 179-183) show a significant increase in Isc and Voc when the system is purged with SiH_4 or Si_2H_6 between the n+ and intrinsic depositions. A 30 minute purge was effective in minimizing the effects of cross contamination with phosphorus.

The collection efficiency CE(λ) for two Pt Schottky devices is shown in Figure 3. They were processed identically except the system received a 30 minute purge between the n and i depositions for one device and the other experienced no purge. The unpurged device has higher CE(λ) at short wavelengths but lower CE(λ)at long wavelengths compared to the purged device. We conclude that this is caused by the unpurged device having a smaller space charge region in which carrier collection occurs compared to the purged device. This is a consequence of the residual phosphorous dopant increasing the conductivity of the unpurged i layer. The smaller space charge region causes the unpurged device to have a higher field near the surface which enhances the short wavelength response due to reduced back-diffusion of electrons into the Schottky contact. Long wavelength light generates carriers outside of this region in the unpurged device, hence it has poor long wavelength response compared to the purged device. The purged device had 40% greater Jsc due to higher photon flux available at the longer wavelength compared to the shorter wavelengths. These effects have been noted by many others (1,2). Also consistent with the above is that the unpurged devices had a higher fill factor, but lower Jsc and Voc than devices receiving a system purge prior to the i layer growth.

Both cells show enhanced collection at short wavelengths under ELH bias compared to dark. However, on purged samples the collection efficiencies under light bias and in the dark coincide at the longer wavelengths. Forward or reverse bias voltage changes the field in the i layer for both devices which causes a displacement of the collection efficiency curves. This behavior with light and voltage bias is consistent with data reported by the Exxon group on Pd Schottky barriers on GD material(3).

TABLE 4

EFFECT OF INTRINSIC LAYER DEPOSITION ON CURRENT-VOLTAGE CHARACTERISTICS FOR SCHOTTKY CELLS

Substrate No.	Temp[1] (°C)	Pressure[1] (torr)	Holding[1] Time(s)	Growth[2] Rate (Å/s)	Thickness[1] Å	Purge min/gas	Pt[3] Event	Isc[4] (ma)	Voc (V)
172C	415	24	38	1.3	2500	30/SiH_4	1	.13	0.5
174D	415	24	38	3.1	2300	30/SiH_4	1	.13	0.48
170D	415	24	38	2.1	3200	30/SiH_4	1	.11	0.48
173D	415	24	38	3.0	3400	30/SiH_4	1	.14	0.45
184D	415	24	38	1.7	3200	30/SiH_4	3	.18	0.54
175D	425	24	38	3.2	3800	60/SiH_4	2	.12	0.52
176D	425	24	38	3.8	4600	30/SiH_4	2	.13	0.5
177D	425	24	38	3.4	4100	10/SiH_4	3	.20	0.56
178D	425	24	38	2.7	3200	none	2	.08	<0.4
180D	425	24	38	5.0	4200	30/Si_2H_6	3	.22	0.57
179D	425	24	38	3.7	3500	20/Si_2H_6	3	.22	0.57
181D	425	24	38	3.4	3700	10/Si_2H_6	3	.19	0.55
182D	425	24	38	3.6	4100	5/Si_2H_6	3	.17	0.52
183D	425	24	38	2.0	2400	none	3	.10	0.37
190C-D	405	24	24	0.9	1300	20/SiH_4	5	.16	0.57
199D	405	36	25	2.3	2200	30/Si_2H_6	5	.11	0.52
186D	435	24	38	3.3	3800	30/SiH_4	3	.22	0.50
193D	435	24	38	4.7	4800	30/Si_2H_6	4	.22	0.54
195D	430	12	11	4.5	3300	30/Si_2H_6	5	.18	0.51
191C-D	430	24	16	12.0	4200	30/Si_2H_6	5	.15	0.55
201D	430	24	16	14.0	5050	30/Si_2H_6	5	.15	0.55
194D	445	24	38	6.0	4400	30/Si_2H_6	5	.21	0.50

[1]Intrinsic layer deposition conditions

[2]May be high due to growth during reactor purge

[3]Same e-beam evaporation

[4]Device area defined by Pt evaporation through 3 mm diameter aperture mask

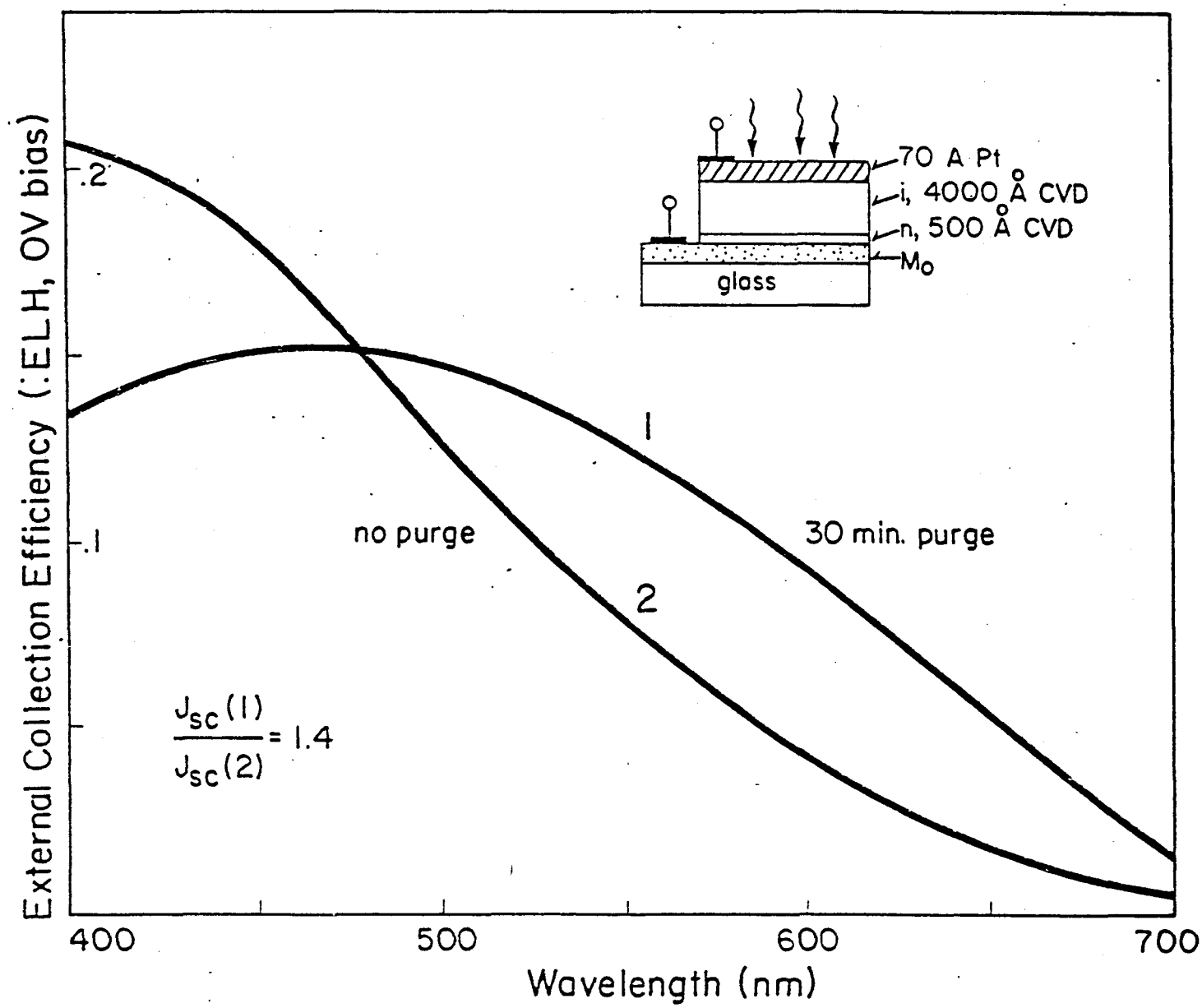


Figure 3 - Effect of a Low Pressure Purge on the Collection Efficiency of CVD Schottky Devices.

The best Pt Schottky devices had Voc = 0.5 V and external Jsc = 2.8 mA/cm^2 at 87.5 mW/cm^2 (ELH). However, Schottky devices were unsuitable for optimizing CVD films due to uncontrolled variations between Pt depositions masking differences between i layers and causing variations in Isc and Voc for the same deposition conditions (for example 170D vs 184D, Table 4).

Furthermore, CVD Schottky devices could not be readily analyzed and compared to GD material for which a baseline of 5-6% n-i-p cells had been established at IEC.

Hybrid nip Devices

Due to the wide variability of the device parameters for Schottky cells with Pt evaporation event, a hybrid device utilizing glow discharge (GD) deposited p+ layers was developed to evaluate the quality of the CVD deposited i layers. Initially the hybrid devices were fabricated by GD depositing a p+ layer on a Mo/7059 glass substrate followed by CVD deposition of the i and n+ layers. The cell area was defined by evaporation of ITO through 3 mm diameter aperture masks. Laser scans of these cells showed a gradual decrease in current response at the edge of the device. Quantitative analysis of these scans showed that the area of the cell based on an area defined by a reduction to 10% of the current response in the center region was 6.8mm^2 while a cut off at 5% of the center response yielded an area of 8.1 mm^2.

To alleviate the problem of poor cell definition subsequent devices were fabricated using photolithography to define 3 mm x 3 mm ITO squares with 0.5 mm nickel tabs to for reliable contacts during repeated testing. The device fabrication procedure is as follows:

1. Clean Mo coated 7059 glass substrate
2. Deposit pin or nip a-Si layers using appropriate process (GD & CVD)
3. E-beam evaporate ITO to coat entire 9 mm x 25 mm substrate
4. Evaporate Ni tab (~2mm wide) along 25 mm dimension
5. Use photo resist to define four - 3 mm x 3 mm squares including 0.5 mm overlap with Ni Tab to define devices with a nominal area of .08 cm^2.
6. Etch unprotected Ni (HF/HNO_3) and unprotected ITO (HCl)
7. Remove remaining photo resist to expose device
8. Etch hole in a-Si at corner of substrate for back contact (to Mo substrates)

A series of deposition (CVD 218-CVD 222) were made to study the effect of i layer and n layer thickness on device performance. Key deposition parameters and layer thicknesses are summarized in Appendix I.

The measured external Jsc for devices fabricated on substrates from CVD218 through CVD 222 versus thickness of i layer are plotted in Figure 4. Other parameters for each device on these substrates are also shown in Appendix I.

The highest and lowest currents occurred in the coolest (400°C, sample 221.51) and hottest (445°C, sample 222.71) substrates respectively. On each substrate there is a significant variation of J_{sc} with i layer film thickness usually with a trend toward higher J_{sc} with thinner i layers.

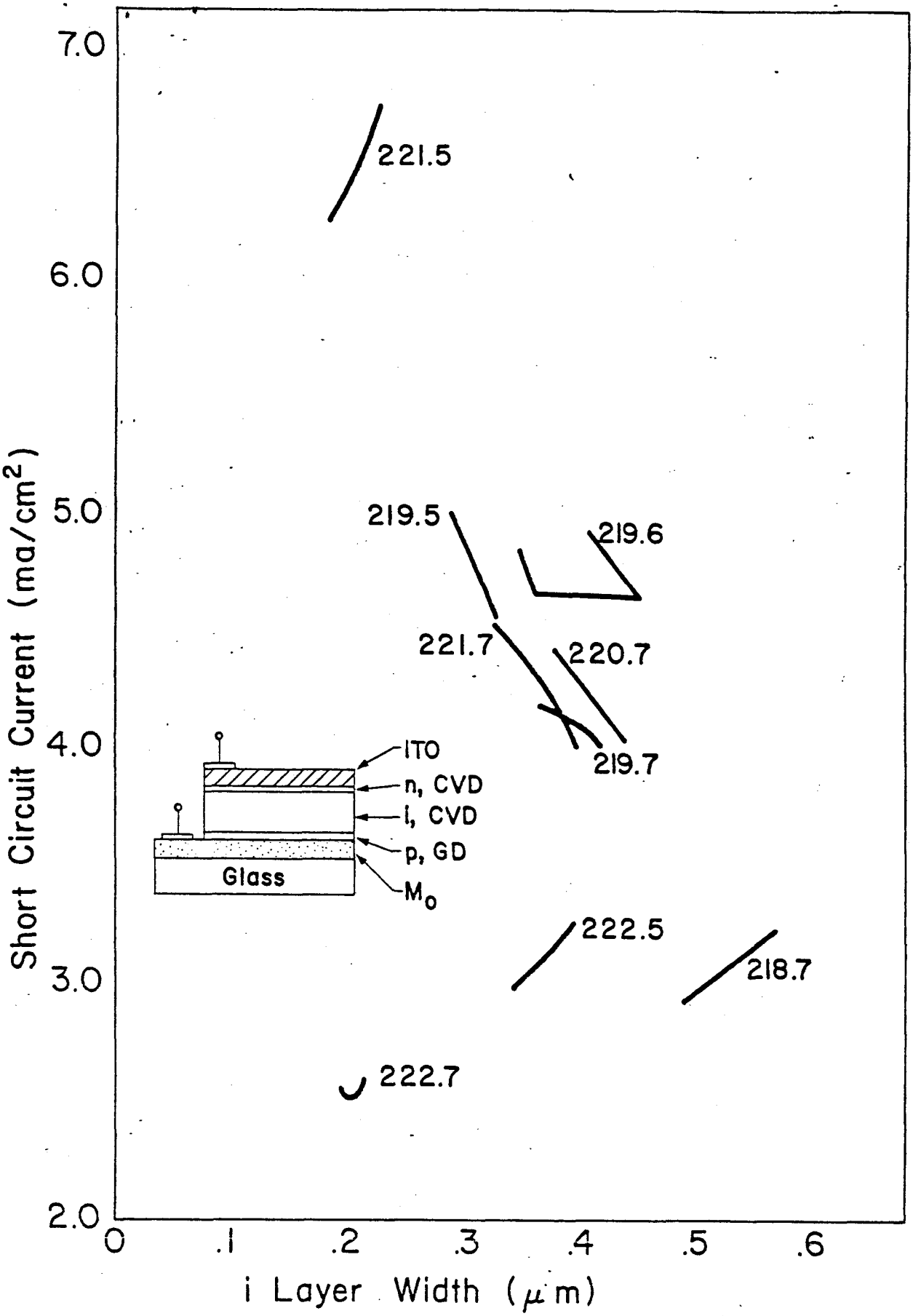


Figure 4. Effect of i Layer Wide on Short Circuit Current Density for Hybrid ITO/nip/Mo Cells.

The effect of the n+ film as the window layer is shown in the spectral response curves in Figure 5. Cell 220.71-4 with a 100Å n layer exhibits approximately 10% higher J_{sc} than 219.71 with a 300Å n layer(4.4 vs 4.1 ma/cm^2) apparently due to higher transmission at the wave lengths up to 650 nm.

The best cell 221.5-4 had a measured short circuit current of 6.7 ma/cm^2 with a V_{oc} of 0.48V and FF of.36. The measured IV characteristics in the light and dark are shown in Figure 6. The device remained stable over the 6 days while stored in air under room light.

In another series of depositions (CVD 230-CVD 235), a matrix of i layer deposition temperature and p+ layer thickness was completed with i layers deposited at 390°C and 400°C on GD p+ layers of 200 Å, 450 Å and 900 Å.

Typical parameters for these nip devices were (87.5 mw/cm^2 ELH):Jsc=4.5-5.8 ma/cm^2, Voc= .5-53V, FF=.35-.40 and ~1% efficiency. They showed no strong trends with the p+ thickness or with the 10° C change in i layer deposition temperature. Deposition conditions, device structure, and cell results for these are summarized in Appendix II.

The i layer thickness(W_i) on the ITO/ni(CVD)/p(GD)Mo/7059 glass devices studied ranged from 1000 Å to 6000 Å. Frequently a factor 2.5 or more in i layer thickenss was obtained in a single deposition as a function of position in the CVD reactor with the thinnest nearer the inlet (substrate xxx.41). As shown in Figure 4 and confirmed by the later runs, the external short circuit current consistently showed a maximum with i layers between 1500Å and 2000Å thick. Below 1500Å, the cell is limited by insufficient depth in which to absorb the light. The reason for the fall-off in J_{sc} for intrinsic layers thicker than 2000Å is most likely low collection length $L_c=\mu\tau E$. This is confirmed by the strong enhancement of the collection efficiency with reverse voltage bias as shown by the spectral response measurements in Figure 7 for our best nip device (CVD 221.51-4).

The ITO/ni(CVD) p(GD)/Mo device parameters changed with heat treatment and storage. During storage, some showed J_{sc} degradation while others were stable over periods of 1 to 15 days even with storage in room light. Changes in device parameters were measured following up to two 180°C heat treatments. These data are included in Appendix II. Significant observations from the heat treatment of hybrid nip cells are:

1. Cells are not in optimum condition during initial test, which is usually the same day as the ITO lithography. Most cells improved beyond initial J_{sc} with 1 hour in air or H_2 and those which received a second treatment continued to improve.

2. There was no clear difference between heat treatment in air or H_2.

3. Some cells continued to improve with room temperature storage in a dark dessicator.

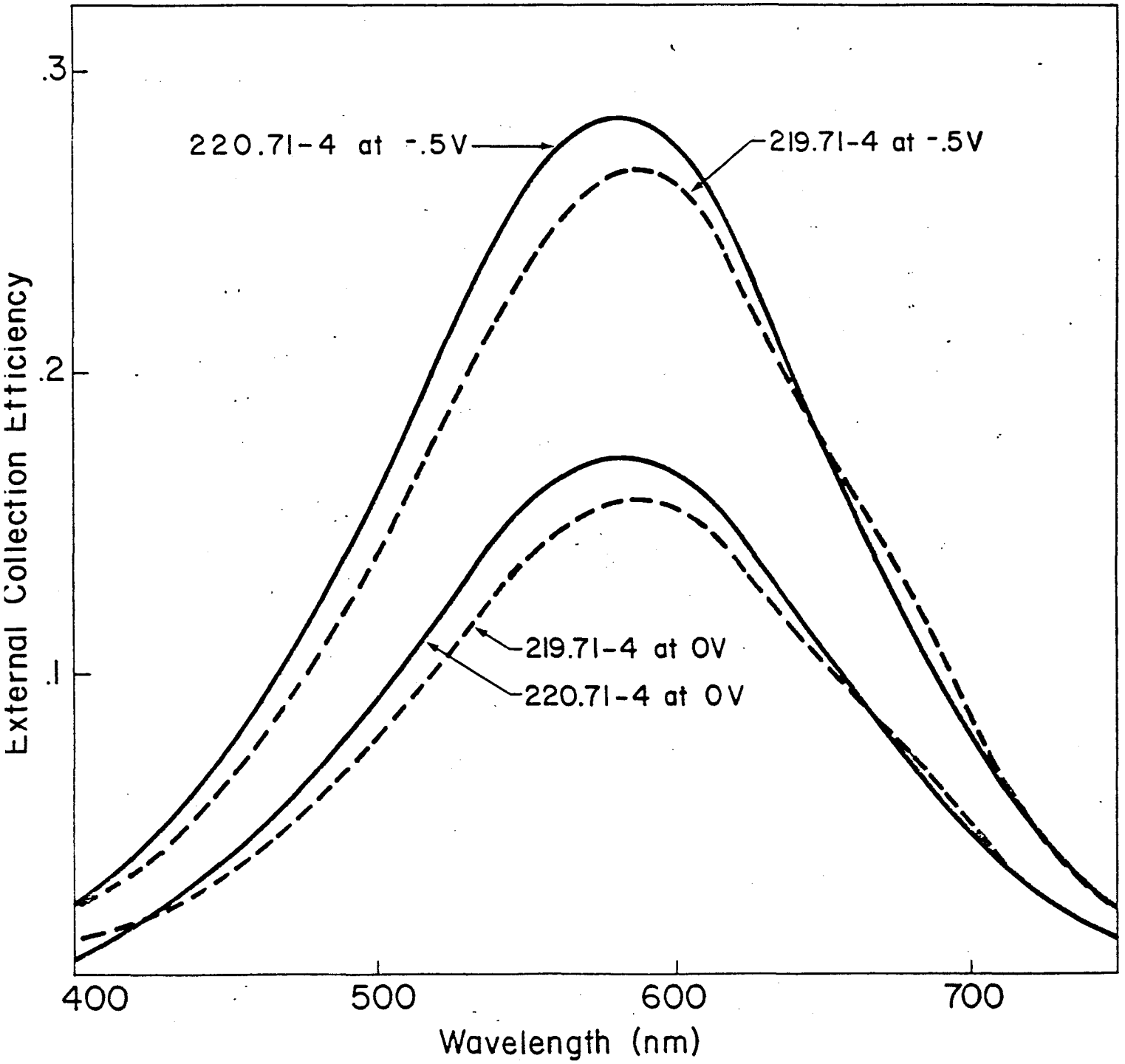


Figure 5 - Effect of n+ Thickness as Window Layer of Hybrid nip, ELH Bias (220.71= 100Å n+, 219.71=300Å n+).

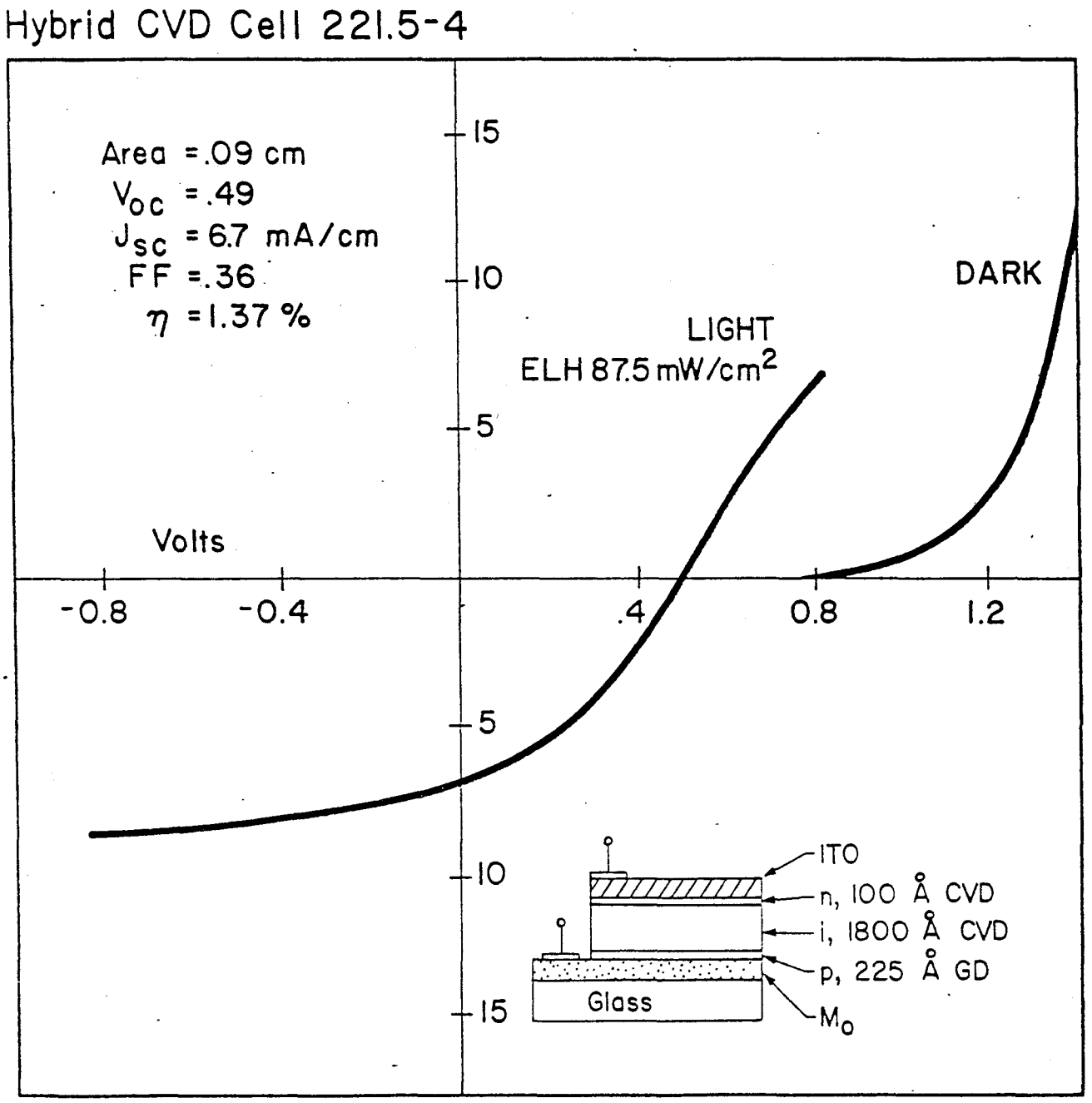


Figure 6 - Current-Voltage Characteristics of Best Hybrid ITO/nip/Mo Cell.

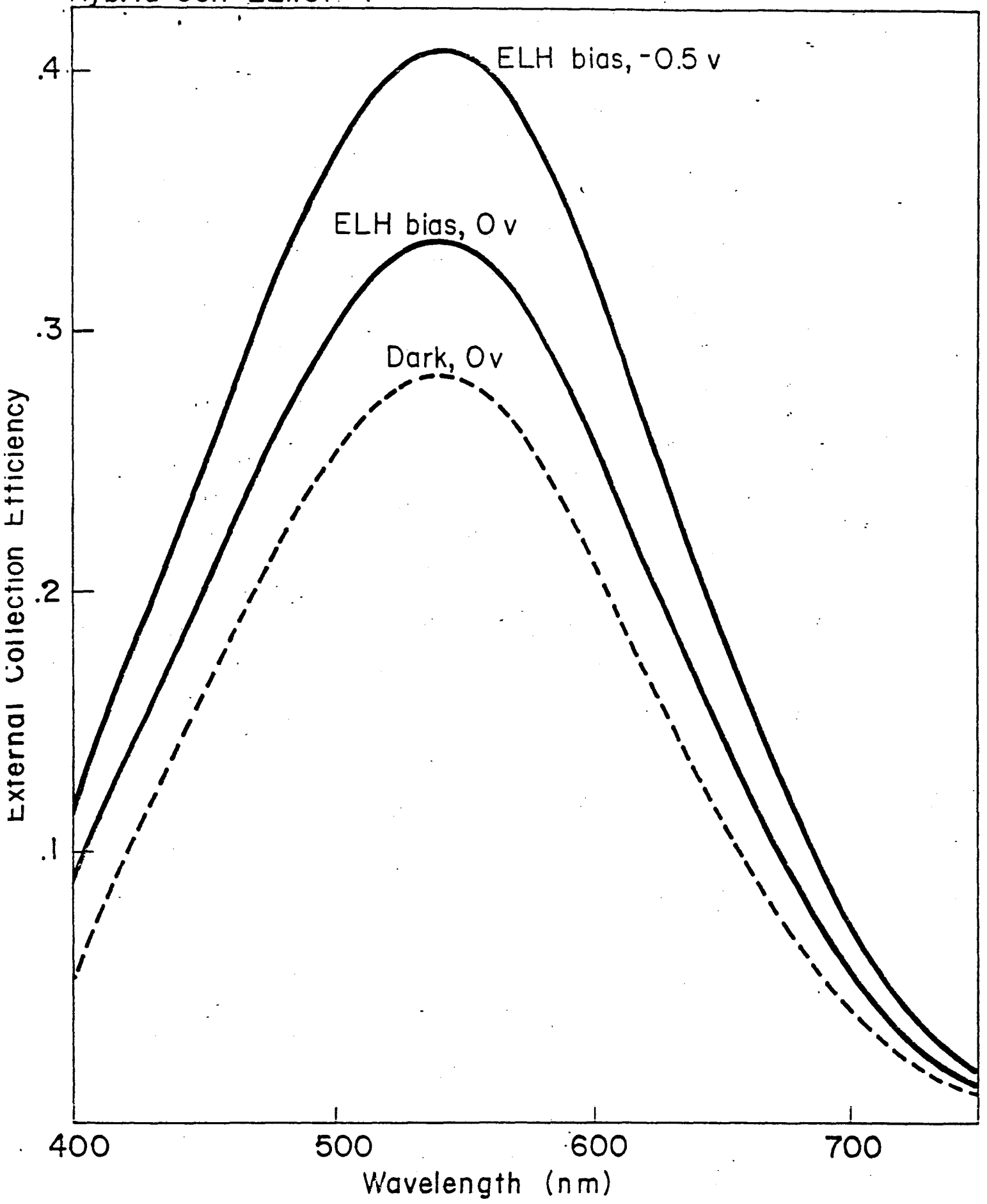


Figure 7 - Effect of Light and Voltage Bias on Highest Efficiency Hybrid ITO/nip/Mo Cell.

4. Improvements in efficiency of over 10% are possible at the end of a total of six hours heat treatment.

The reasons for the changes with heat treatment and storage and the variation in these changes are not known at this time. Possible causes are: stress relief, contact resistance reduction, filling of traps with thermally generated carriers, and modifying the hybrid interface.

Hybrid pin Devices

Hybrid devices with GD p type a-Si:H deposited on CVD in/Mo/7059 glass were also studied. These cells have been fabricated with large variations in deposition conditions and thicknesses of the various layers. These include:

1. GD p type films between 80 and 335Å thick deposited at 250°C and 300°C.

2. CVD intrinsic films between 1000 and 6000Å thick at substrate temperatures from 380°C to 420°C and growth rates ranging from less than 0.2 Å/S to greater than 4 Å/S.

This structure resulted in a high yield of good devices that have been suitable for analysis and optimization. Compared to the hybrid ITO/nip/Mo cells the pin cells were characterized by significantly higher Voc and FF, comparable currents, and very little crossover between the light and dark IV curve, indicative of a better quality device (i.e. fewer traps, higher conductivity i layer, etc.)

Devices have been analyzed and optimized based on:

1. comparison of current-voltage characteristics as a function of deposition conditions and film thicknesses (p+ and i layers)

2. analysis of the dependence of the collection efficiency on voltage bias and wavelength, $CE(V,\lambda)$, to determine the relative transport properties of electrons and holes in the CVD i layers.

3. measurement of $1/C^2$ vs V at 150°C to estimate the defect density

4. calculation of mobility lifetime($\mu\tau$) product

Figure 8 shows the typical dependence of short circuit current and cell efficiency on i layer thickness. Each line represents the results of 16 devices on 4 substrates located at different axial positions in a common CVD ni deposition. The fill factors decrease with intrinsic layer thickness from .50 to .46 and from .49 to .43 for the 400°C and 420°C i layers respectively. V_{oc} is approximately constant(increasing slightly over these thicknesses); typically Voc=.71 - .73 V. Detailed deposition conditions and device performance are shown in appendix III for these substrates.

Capacitance-voltage measurements ($1/C^2$ vs V) were made at 150°C at frequencies from 0.4 to 10 Khz. The space charge density estimated from these measurements was found to be 10^{16}-10^{17} cm^{-3} independent of the i layer deposition temperature over the range studied (380 - 420°C). The space charge is due to traps and unintentional impurities either in the disilane or from the phosphorous deposition prior to the i layer deposition.

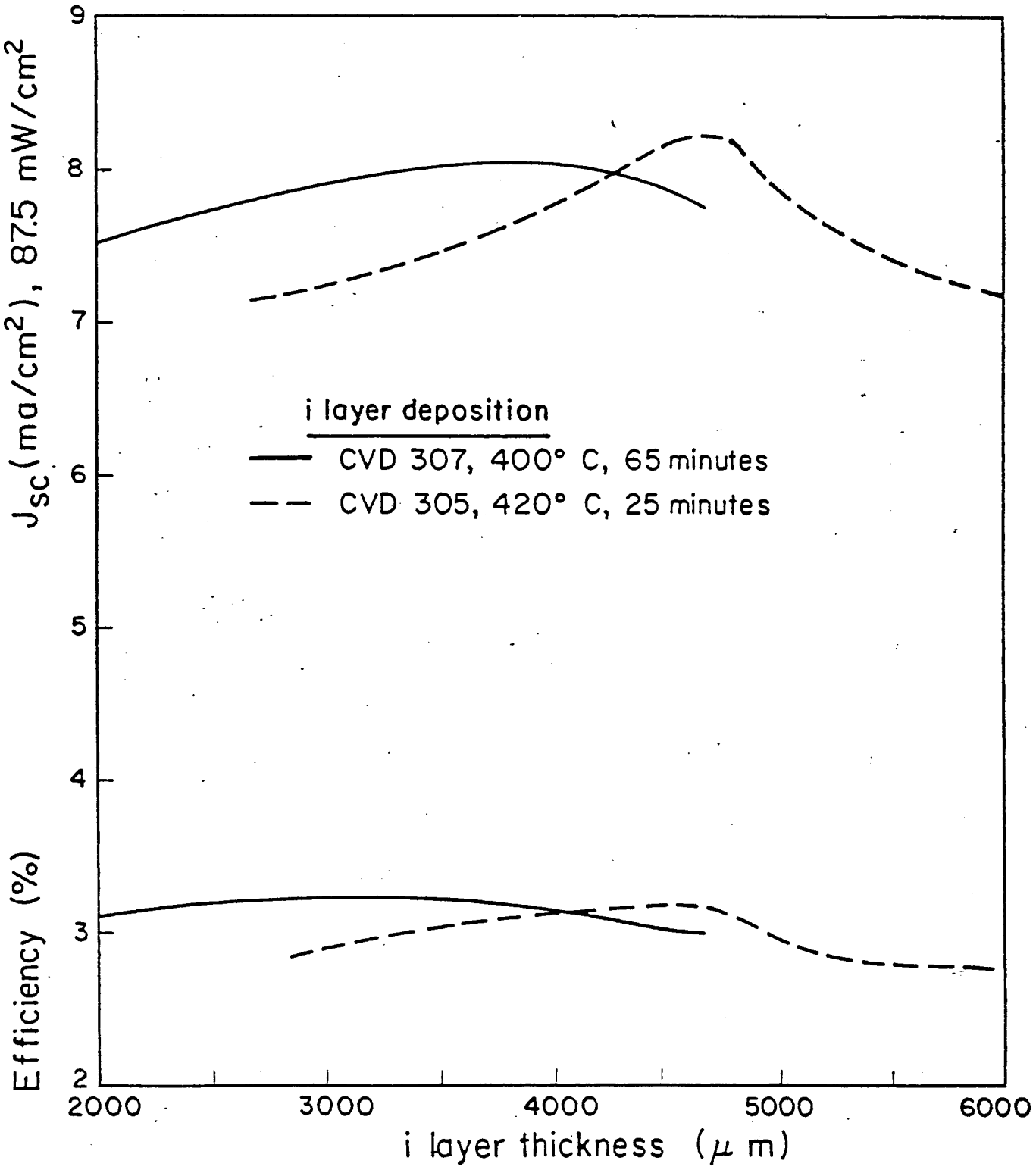


Figure 8 - Dependence of Short Circuit Current Density and Efficiency on i Layer Thickness for Hybrid ITO/pin/Mo Cells.

The mobility lifetime product ($\mu\tau$) was determined for material grown over a range of deposition conditions from measurement of long wavelength photogenerated current as a function of bias voltage in the manner described by Crandall.(4) These measurements yielded $\mu\tau$ values of 2-8 x 10^{-9} cm^2/V which indicate a zero bias collection length $L_c=\mu\tau E$ of 0.5-1μm. The dependence of $\mu\tau$ on i layer width indicated that the $\mu\tau$ was proportional to the i layer thickness.

Devices over 3% have been fabricated at several substrate temperatures and over the range of film growth rates. Few definitive trends were seen as a function of substrate temperature or growth rate, partly due to the many changes in device fabrication and sample handling which occurred simultaneously . These parameters will continue to be monitored for optimization as device performance improves and fabrication procedures are standardized.

The short circuit current increased as the p+ window layer thickness decreased and also increased with a decrease in the GD p+ bakeout and deposition temperature. This improvement may be a result of better quality window layers at the lower temperature or less dehydrogenation of the i layer during the bakeout period.

The highest efficiency cells of this type to date include three of four from substrate 300.72 between 3.9 and 4%. The CVD n+ and i layers of this substrate were deposited at 420°C and 400°C respectively. The n+ layer thickness is approximately 200 Å . The intrinsic layer thickness is 4000 Å deposited at a rate of 45 Å/minute. The GD p layer was deposited at 250°C and is 100 Å thick. ITO was deposited by electron beam evaporation followed by a 2 hr, 200°C insitu heat treatment in an oxygen rich atmosphere. The area of the rectangular cell is 0.075 cm^2, measured by optical microscope with sharp edges verified by laser scan.

The heat treatment and test history of CVD cells from CVD 300 are also shown in Appendix III. Figure 9 shows the current-voltage characteristics in the light and dark for one of the high efficiency cells on this substrate.The cell efficiency in Figure 9 is 3.95% with Voc=.725V, FF=.495 and external Jsc= 9.6 ma/cm^2 tested under ELH light at 87.5 ma/cm^2. This efficiency was achieved following a 1 hour, 150°C heat treatment in air.

Figure 10 shows the collection efficiency under various light and voltage bias conditions for this device. The ratio of collection efficiency with and without voltage bias,shown as an inset in Figure 10, indicates that the collection length of holes is less than that of electrons in this device. This is typical of our hybrid ITO/pin/Mo devices. It is seen from Figure 10 that the ELH bias light increases the collection efficiency at all wavelengths compared to that measured in the dark. This is opposite to the light and dark behavior of a nip type device, confirmed both by hybrid CVD nip devices made at IEC and on GD nip devices made at other laboratories. This has been further investigated . When the bias light was a very low intensity monochromatic beam (~50μW/cm^2 at 650 nm) the collection efficiency was found to be almost as high as when full ELH bias was used (~87.5 mW/cm^2 of white light). The increase was greatest at short wavelengths. The weak red light

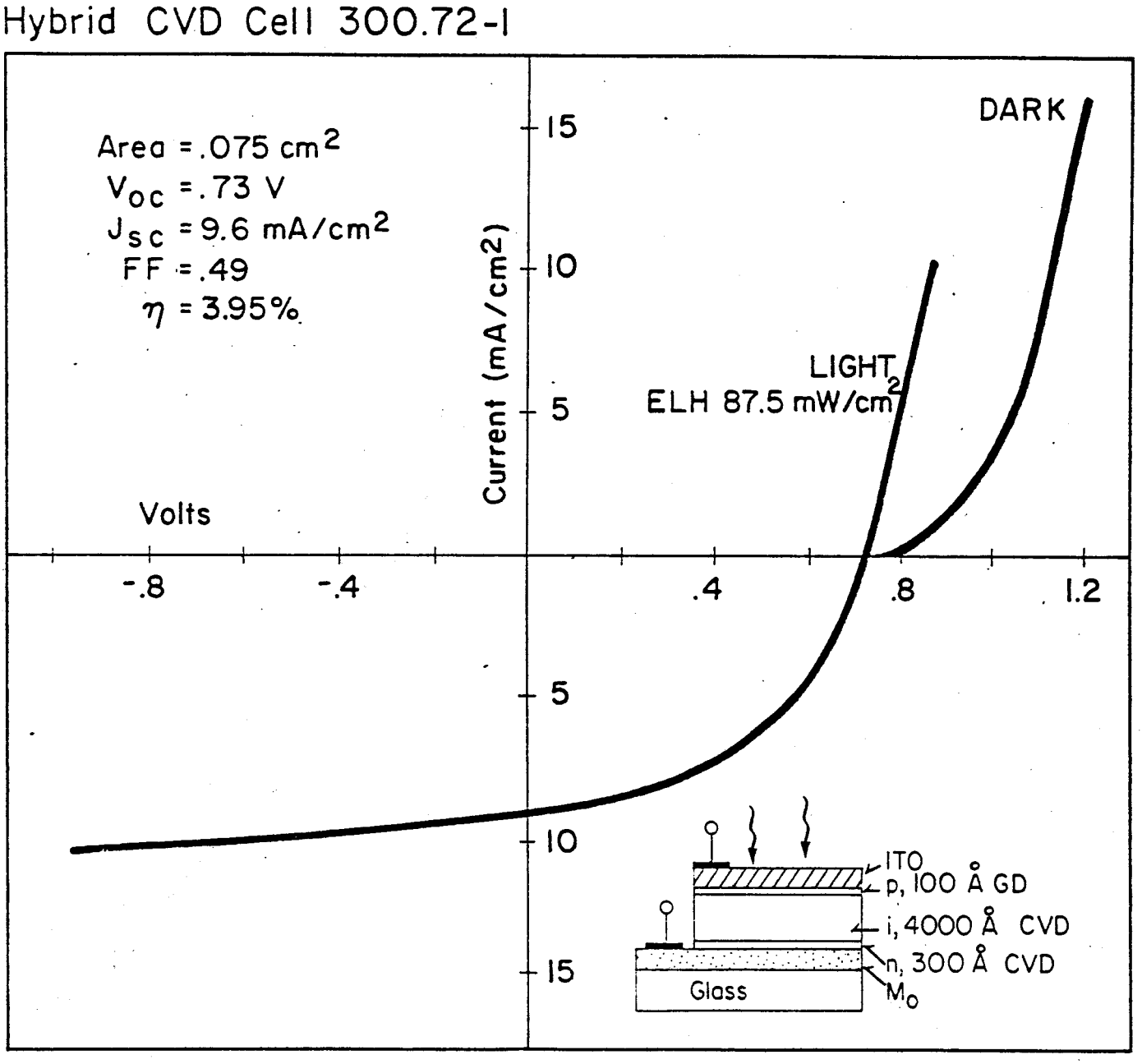


Figure 9 - Current Voltage Characteristics of a Typical Hybrid Cell from Substrate 300.72.

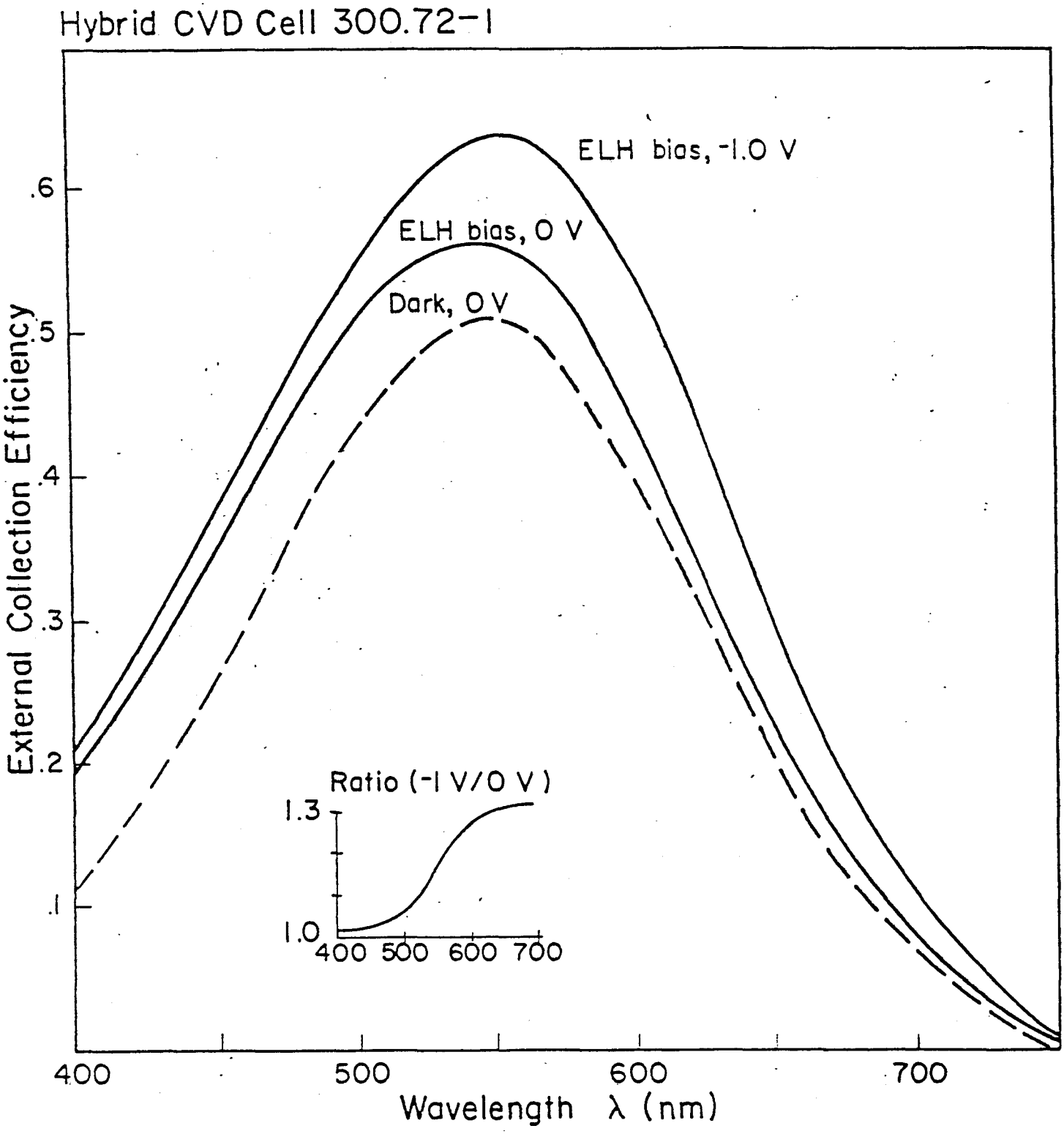


Figure 10 - Dependence of Collection Efficiency on Light and Voltage Bias for a High Efficiency Hybrid ITO/pin/Mo Cell.

is uniformly absorbed in the i layer due to its absorption length. We believe that the change in collection efficiency is due to the red light reducing the series resistance of the portion of the i layer which is not penetrated by the short wavelength probe light during the measurement of collection efficiency in the dark. Note on Figure 10 that the ELH bias light increases the response more at short wavelengths than at long wavelengths compared to the dark response. This effect has also been noticed by others in similar dual-beam measurements (3). Thus the dark spectral response in our pin devices is series resistance limited. The reason for the decrease with ELH bias in nip devices will be investigated further.

The long wavelength photogenerated current Jph measured as a function of voltage bias is shown in Figure 11 for λ=675nm. Analysis of this data using the technique given by Crandall (4) yields a $\mu\tau$ value of 2×10^{-9} cm2/V which implies a zero bias collection length L_c of .34 μm.

Improvements in the quality of CVD intrinsic a-Si:H are expected to increase L_c and improve J_{sc} and FF. Possible loss causes include contaminated disilane and losses attributable to the hybrid pin configuration where the phosphorus doped layer is deposited by CVD first. Future areas of experimentation are described later in this report.

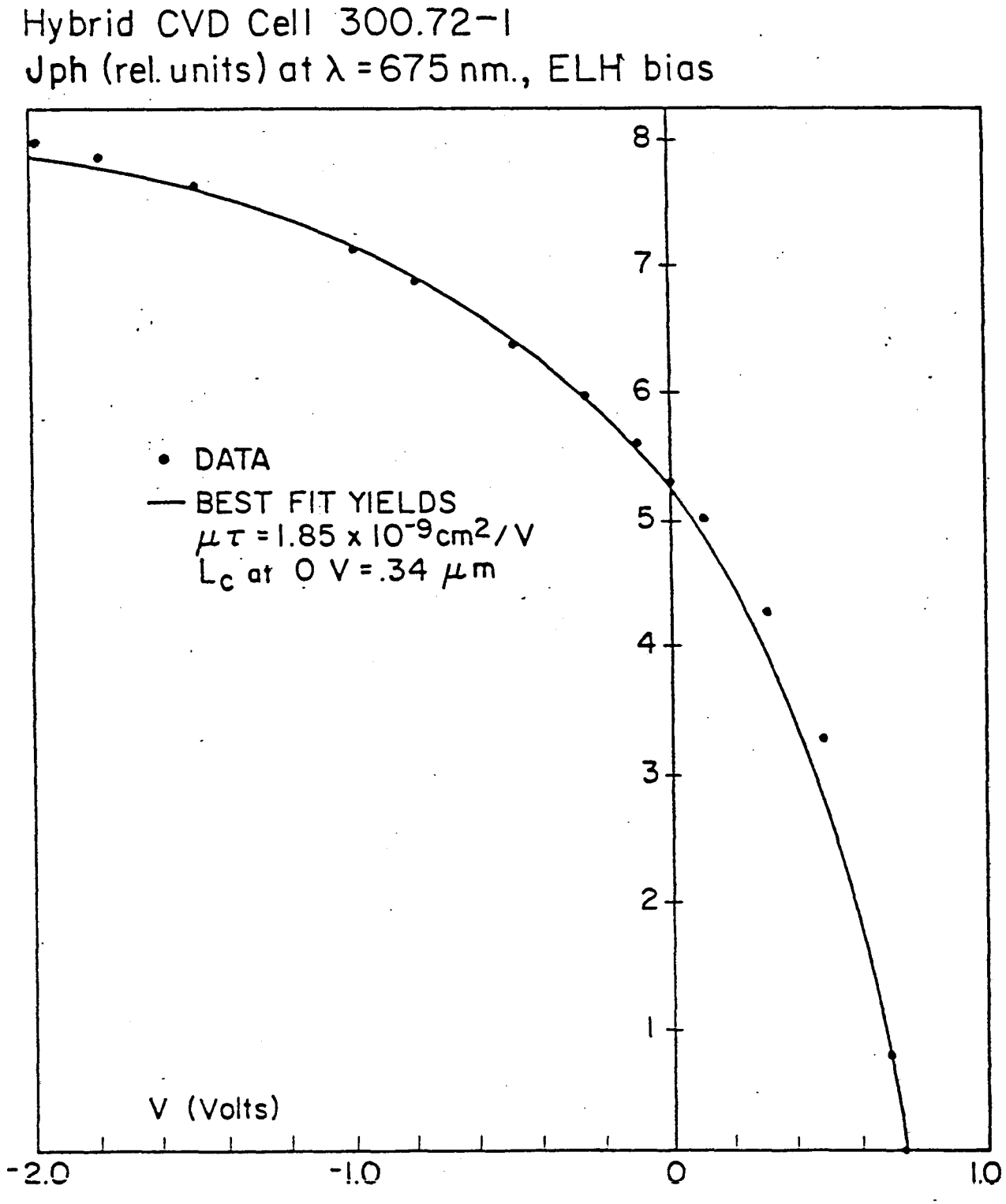


Figure 11 - Best Fit of J_{ph} vs V for μτ Determination.

MODEL DEVELOPMENT

Development of the chemical model for the low pressure CVD of disilane started under SERI Subcontract No. XB-2-02084-1 has continued with the emphasis changing from the analysis and modeling of the gas phase reactions to describing the surface reactions leading to growth of the a-Si:H film. In this section, the basic model equations, chemistry, and solution techniques are reviewed and recent results for describing the rate of film growth presented.

The LPCVD reactor being described is a tubular flow reactor with static substrates. As previously described (QR3, XB-2-02084-1), the reactor is isothermal in the radial direction (wall, gas, and substrate) and has a well defined, experimentally measured temperature profile along the axis of the tubular reactor. The reactor system is described by the mass balance equations summarized in Figure 12. Equation 1 (Fig 12) describes the rate of appearance and disappearance of chemical species in the gas phase where C_i represents the concentration of species i in the gas phase, and r_i the gas phase reaction rates. Equation 2 shows the equivalence between a species leaving (entering) the gas phase by adsorption on the surface and the rate of reaction utilizing (forming) that species. Equation 3 relates the surface reaction rate to the rate of film growth $(d\rho V_f)/dt)$. Based on the results of Ring (5), John and Purnell (6), and Bowrey and Purnell(7), the inlet mixture of silane gases udergo the following reactions in the gas phase:

$$Si_2H_6 \rightleftharpoons SiH_4 + SiH_2$$

$$Si_3H_8 \rightleftharpoons Si_2H_6 + SiH_2$$

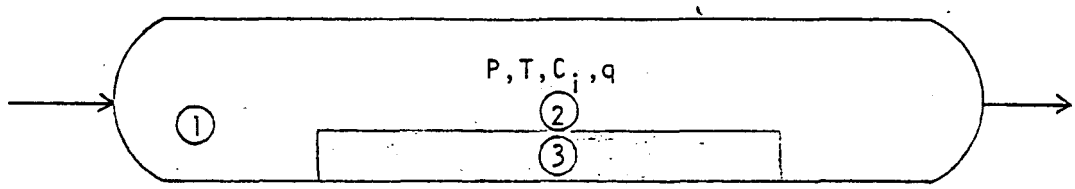
$$Si_4H10 \rightleftharpoons Si_3H_8 + SiH_2$$

$$Si_5H_{12} \rightleftharpoons Si_4H_{10} + SiH_2$$

In the present model, mass balances accounting for H_2 and all saturated silane species through Si_8H_{18} have been included.

A key part of the model development is to determine and verify a contitutive expression describing the rate of film deposition. To accomplish this the gas composition must be known at each reactor location. An estimate of the gas composition has been obtained by uncoupling the solution of the gas and solid phase mass balances (1 and 3, Fig 12) using the logic outlined in Figure 13. In this procedure, the experimentally determined film growth rate $(d\rho V_f/dt)$ is input to the gas phase equations, eliminating the need for a kinetic surface rate expression. However, as indicated by this diagram, the calculated gas composition can depend on the chemical species involved. As will be discussed in more detail later, this is especially important when surface reactions involving silane species greater than pentasilane are considered.

As described earlier (QR3, XB2-20284-1), the gas phase equations were solved by modelling the laminar flow ractor as a series of small equal volume well mixed reactors. The axial temperature profile and the molar expansion due



$$\textcircled{1} \quad \mathcal{D} \frac{\partial^2 C_i}{\partial z^2} + u \frac{\partial C_i}{\partial z} = \sum r_i + k_g a \, [C_i - C_{i_s}]$$

$$\textcircled{2} \quad 0 = k_g a \, [C_i - C_{i_s}] - \frac{a \, K \, k_s \, C_{i_s}}{1 + \sum K_j C_j}$$

$$\textcircled{3} \quad \frac{1}{mw} \frac{d \, \rho V_f}{d \, t} = \frac{a \, K \, k_s \, C_{i_s}}{1 + \sum K_j C_j}$$

Figure 12 - Mass Balances Describing Gas Phase, Impingement Region, and Condensed Phase in CVD Process.

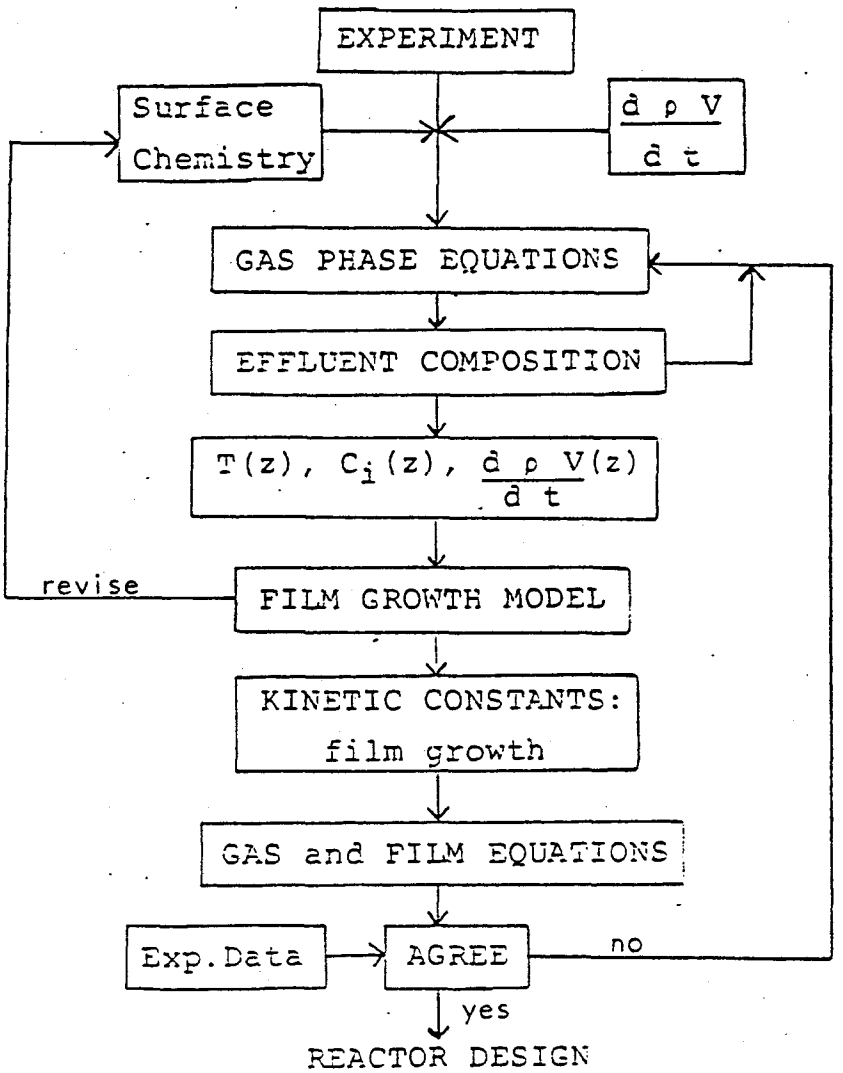


Figure 13 - Logic Diagram for Separation of Gas Phase Reactions and Film Growth Rate.

to the production of hydrogen are accounted for in the solution of the model equations. The coupled non-linear mass balances for each segment are linearized by iterating on the silylene (SiH_2)concentration as shown in Figure 14, greatly simplifying their solution.

The chromatographic analysis of the effluent was described in QR 3 of XB-2-02084-1. The calculated effluent composition including H_2 and the silane species up to tetrasilane based on the locally matched growth rate model and that determined by chromatography are compared in Figures 15 and 16 for data at 24 torr and nominal reactor temperatures of 400°C and 420°C. The changes in composition with gas holding time (gas flow rate) are predicted quite well.

Based on the good agreement of the model and chromatographic data at the effluent we feel justified in using the calculated gas composition in each reactor segment to determine the dependence of film growth rate on gas composition and temperature. Figure 17 shows typical results of film growth rate plotted against the concentration of disilane, trisilane and tetrasilane. The data were obtained at a fixed position 14 cm from the inlet at 400°C, 24 torr. Gas composition was varied by changing the volumetric flow rate (gas holding time) over the range from 0.3 to 3 ccm (62-8 seconds holding time). As shown in this figure growth rate is most closely correlated with the concentration of tetrasilane and least correlated with the disilane concentration. Based on these correlations, several kinetic expressions representing growth from Si_4H_{10} were tested in the model equations. While the fit to experimental growth rate data was much improved over earlier attempts using disilane or trisilane, even with Langmuir-Hinshelwood type kinetic expressions it was not possible to obtain a good fit to the data as gas holding time, axial position and temperature were all varied.

Based on the improvement and observed similarities to published results describing coking from hydrocarbon pyrolysis (8,9)two other reaction models for film growth involving higher order silanes have been evaluated. Both included the same gas phase reactions described earlier.

The first was based on the reaction of silanes heavier than pentasilane with the creation of hydrogen and lower order silanes described by:

$$Si_6H_{14} \longrightarrow SiH_x + (1-x/2)H_2 + Si_5H_{12}$$

$$Si_7H_{16} \longrightarrow SiH_x + (1-x/2)H_2 + Si_6H_{14}$$

$$Si_8H_{18} \longrightarrow SiH_x + (1-x/2)H_2 + Si_7H_{16}$$

For simplicity the growth rate was estimated as

$$\frac{1}{mw}\frac{d\rho V_f}{dt} = k_s \left\{ [Si_6H_{14}] + [Si_7H_{16}] + [Si_8H_{18}] \right\}$$

It was found that the predicted growth rate was consistently low and showed slightly less dependence on axial position than the measured growth rates. Significant increases in the surface rate constant resulted in only

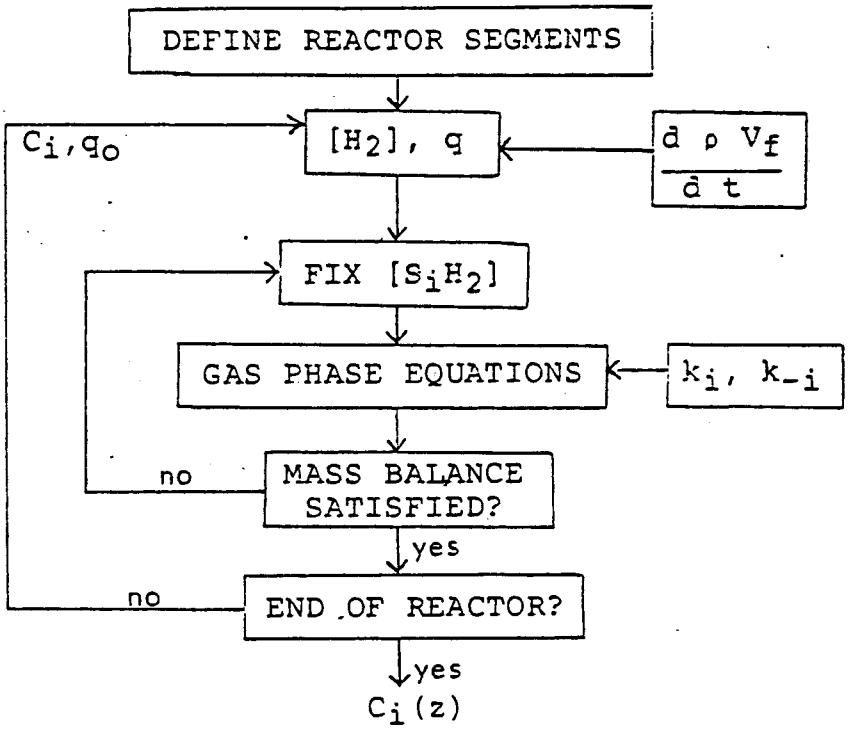
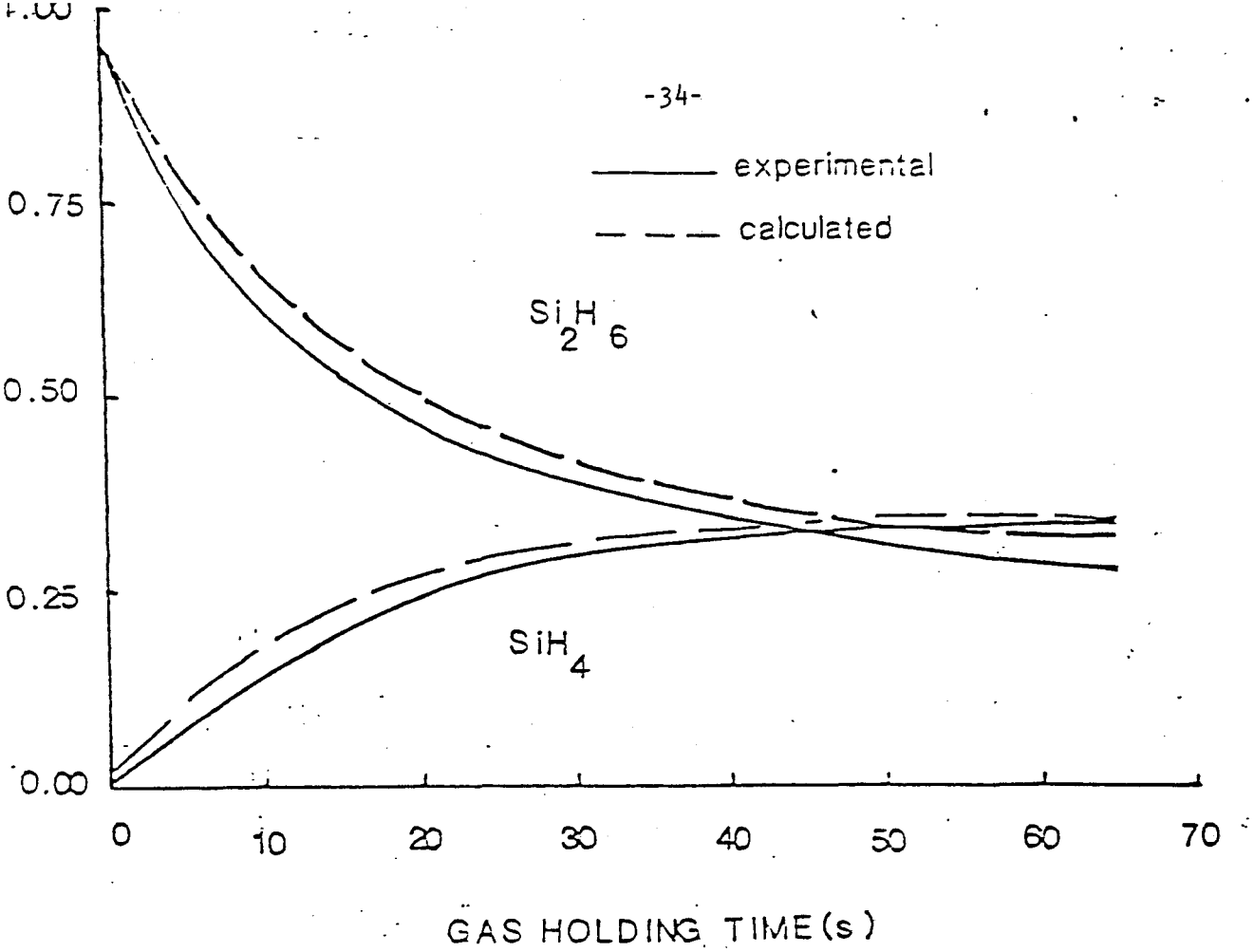


Figure 14 - Logic Diagram Describing the Solution of Gas Phase Equations with Specified Film Growth Rates.



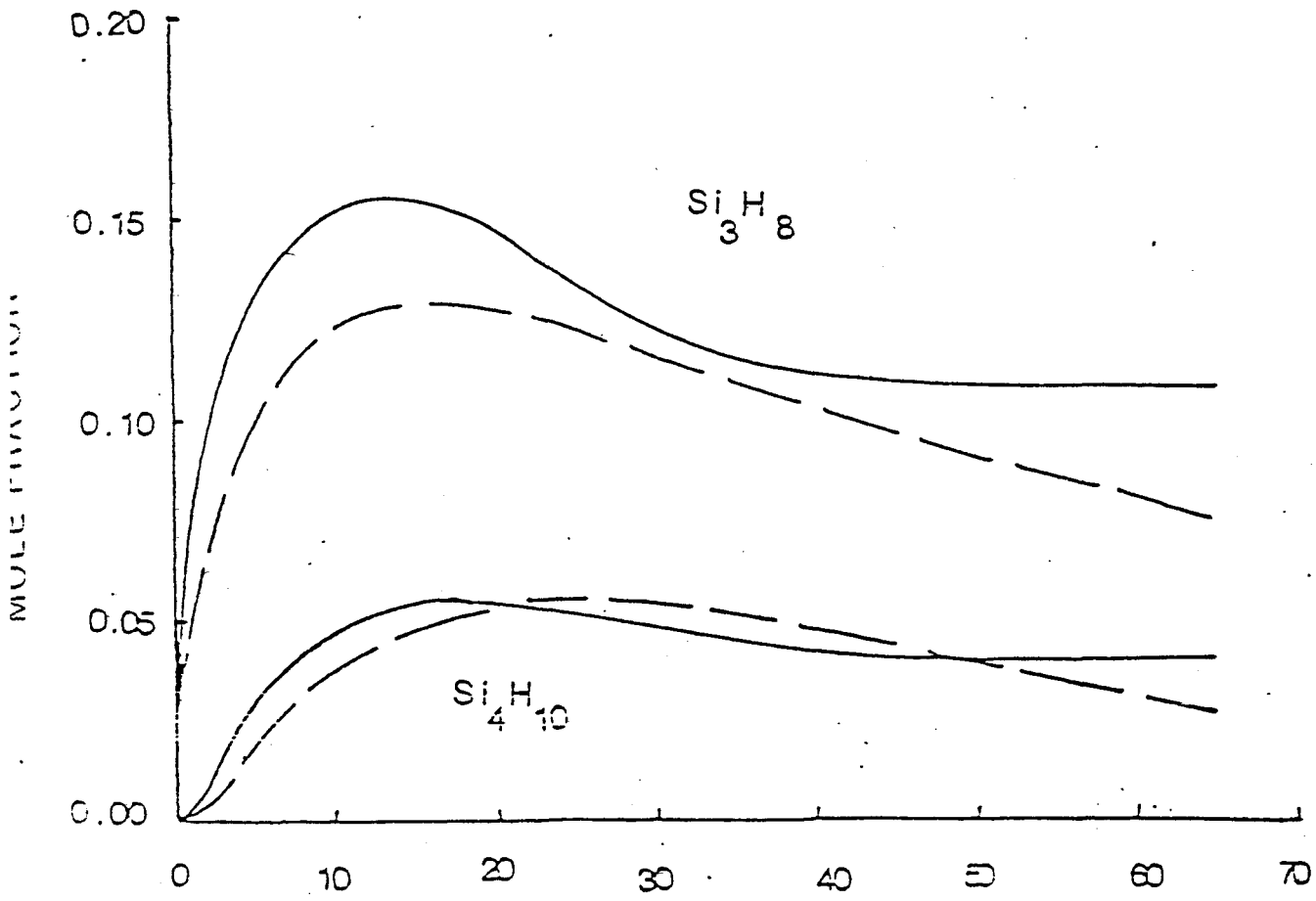


Figure 15 - Comparison of Model Behavior and Measured Effluent Composition (Reactor Temp = 400°C, Pressure=24 torr)

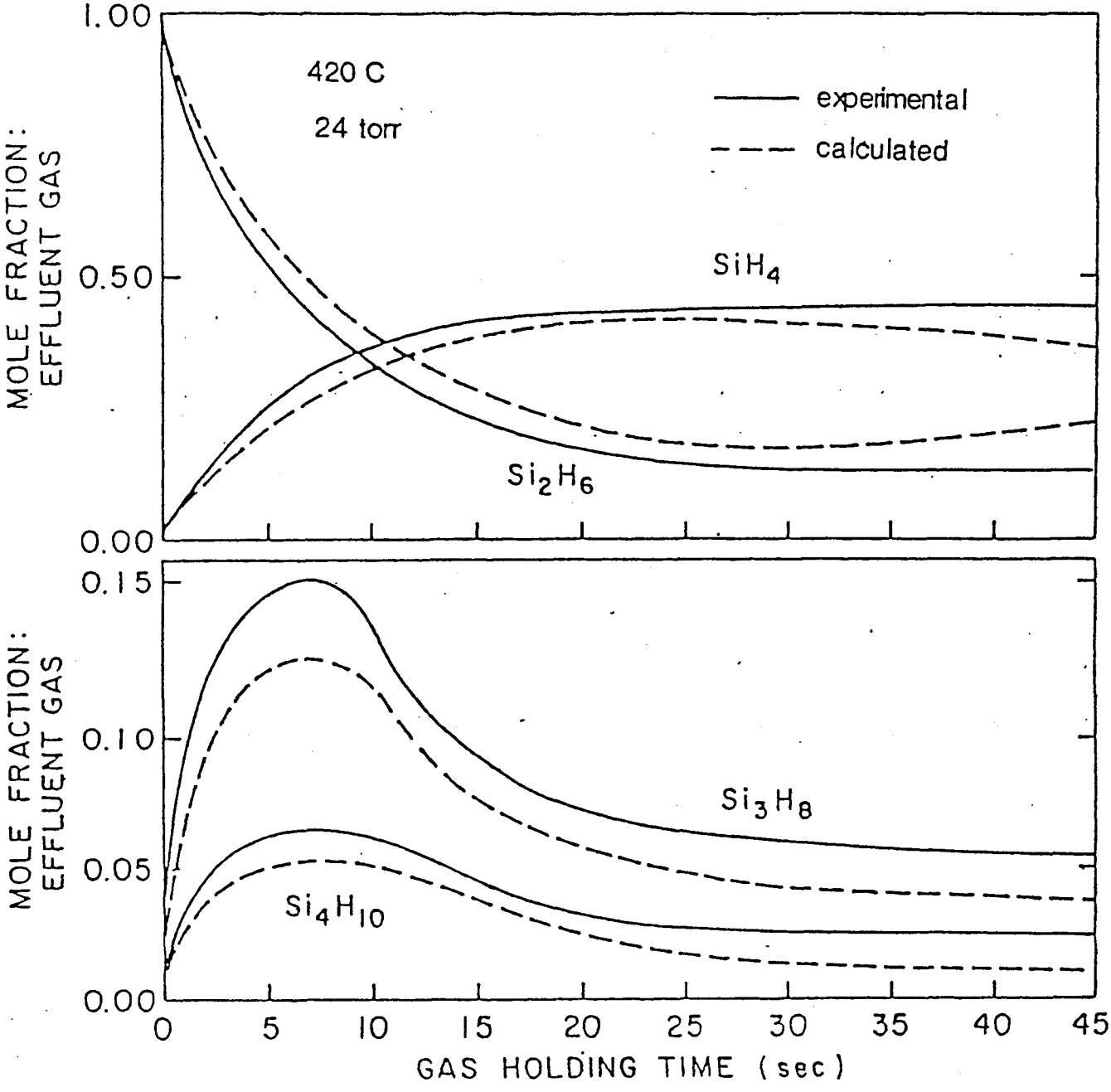


Figure 16 - Comparison of Model Behavior and Measured Effluent Composition (Reactor Temp = 420°C, Pressure = 24 torr).

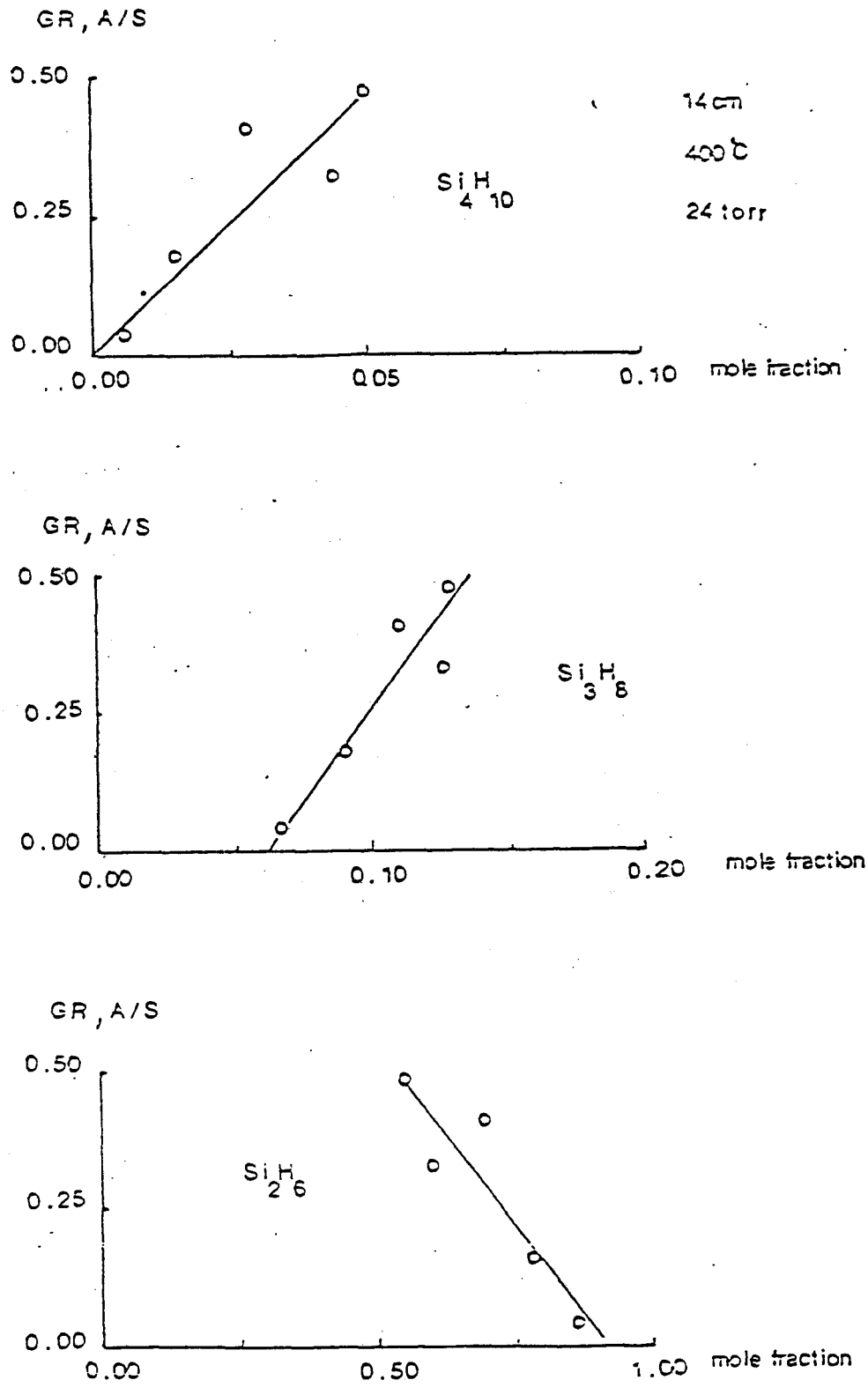


Figure 17-Dependence of Film Growth Rate on Concentration of Higher Order Silanes (14 cm from inlet, 24 torr, 400°C).

moderate increases in the calculated growth rate due to depletion of these higher order species.

The second surface reaction model evaluated was based on the complete reaction of the high order species on the surface with hydrogen as a byproduct as detailed below.

$$Si_6H_{14} \longrightarrow 6\ SiH_x + (6-3x)H_2$$

$$Si_7H_{16} \longrightarrow 7\ SiH_x + (7-7x/2)H_2$$

$$Si_8H_{18} \longrightarrow 8\ SiH_x + (8-4x)H_2$$

with the growth rate described by

$$\frac{1}{mw}\frac{d\rho V_f}{dt} = k_s\left\{6[Si_6H_{14}]+7[Si_7H_{16}]+8[Si_8H_{18}]\right\}$$

Preliminary evaluation of this simple kinetic expression has been made by comparing the calculated and measured film growth rate over a wide range of deposition conditions including:

1. different axial positions encompassing a 20°C temperature difference in each run.

2. nominal (center-point) reactor temperatures ranging from 380°C to 450°C

3. reactor pressure from 2 to 48 torr

4. gas holding times from 4 to 65 seconds (gas flowrates from 0.37 to 3.5 sccm)

The preliminary evaluation was done by preselecting a reasonable surface rate constant with an activation energy comparable to that for the gas phase reactions (49.2 kcal/gm-mole).

This model does an excellent job of predicting film growth rate in the following cases:

1. At reactor temperatures up to 400°C (Figure 18 and 19).

2. At pressures below 10 torr even at high temperature (Fig. 20).

3. As a function of pressure (Figures 20 and 21).

The model does not do as well at intermediate to higher temperatures (T>420) with pressure around 24 torr (Figure 22). As shown in Figure 22, the difference is greatest near the exit of the reactor in the region of decreasing substrate temperature. However in this region hazy films, particulate and poor adherence are sometimes observed indicating that other types of surface reactions may begin to be rate controlling.

At present the simple model accounting for film growth by condensation and dehydrogenation of the higher silanes predicts film growth rates remarkably well over the wide range of deposition conditions surveyed. No effort has yet been made to improve the agreement by optimizing the surface or gas phase rate constants or by using separate rate constants for each of the reacting species. Significant improvements can be expected with this type of optimization

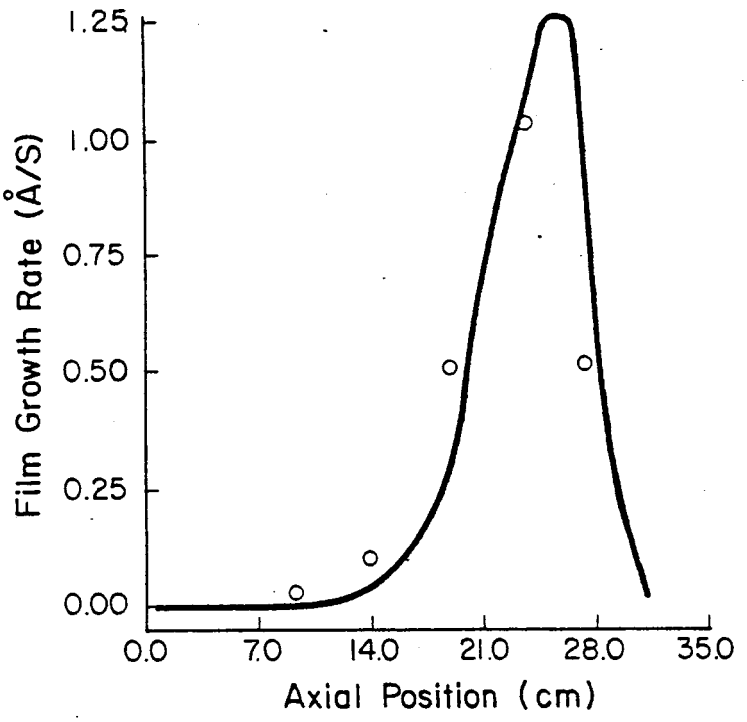


Figure 18a - Film Growth Rate for CVD 242 (400°C, 24 torr, 14.9s gas holding time; O=measured, — = calculated)

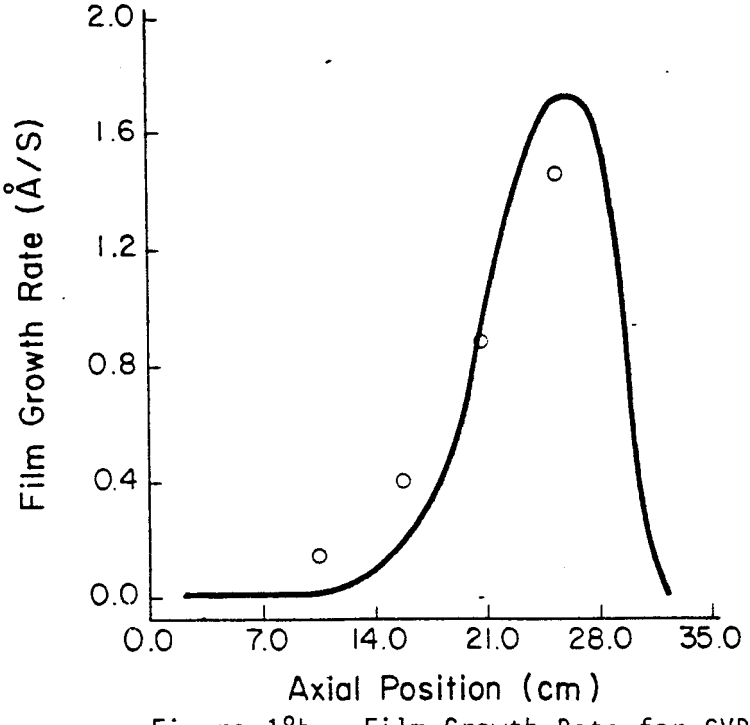


Figure 18b - Film Growth Rate for CVD 244 (400°C, 24 torr, 26.8s gas holding time; O=measured, — = calculated).

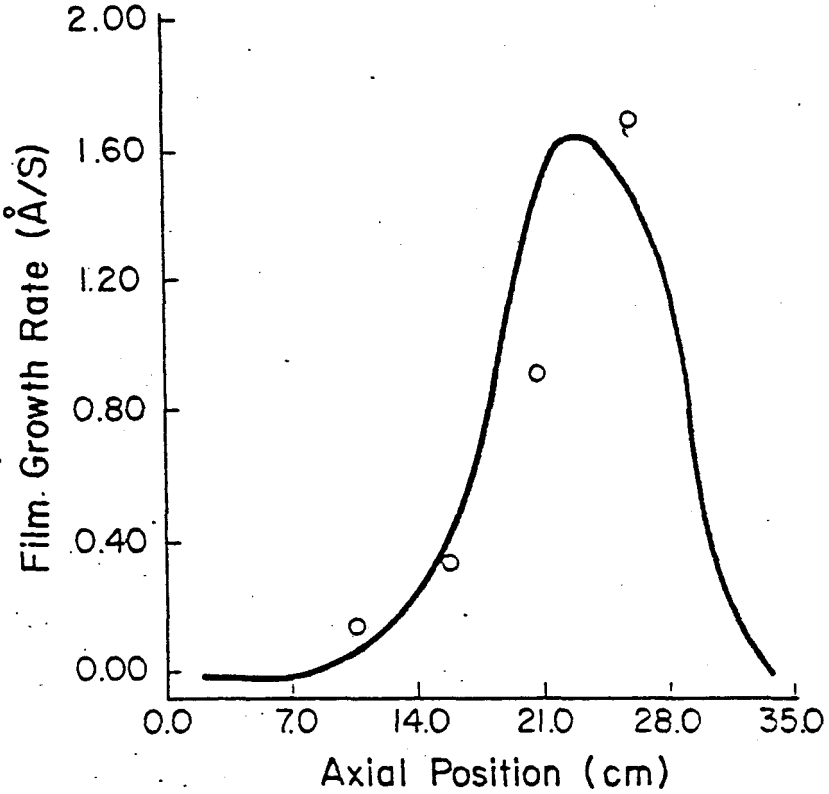


Figure 19a - Film Growth Rate for CVD 241 (400°C, 24 torr, 44.7 s gas holding time; 0=measured, — = calculated.

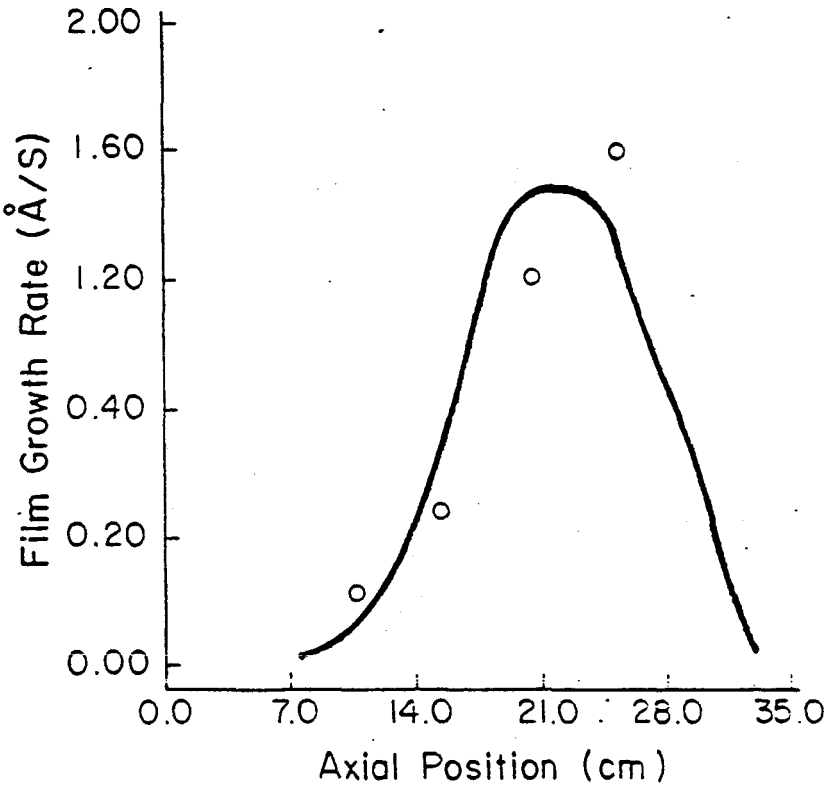


Figure 19b - Film Growth Rate for CVD 243 (400°C, 24 torr, 62 s gas holding time; 0=measured, — = calculated)

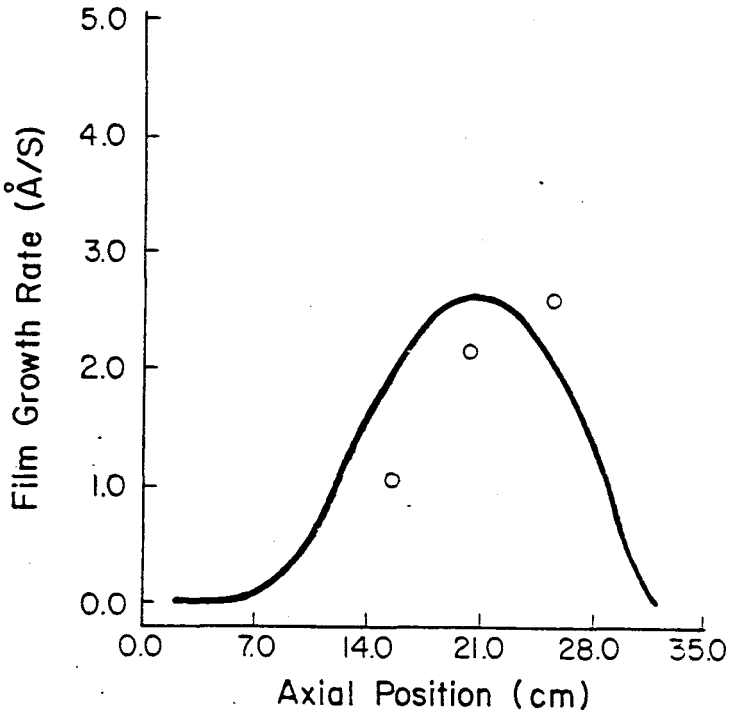


Figure 20a - Film Growth Rate for CVD 40 (450°C, 4.2 torr, 6.4s gas holding time; O=measured,— = calculated)

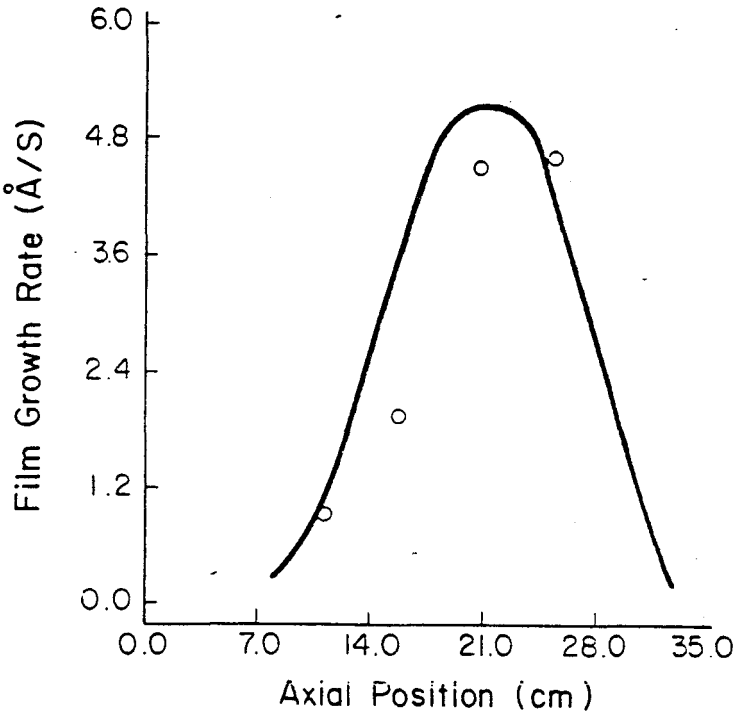


Figure 20b- Film Growth Rate for CVD 51 (450°C, 8.4 torr, 6.8 s gas holding time; o=measured,— = calculated)

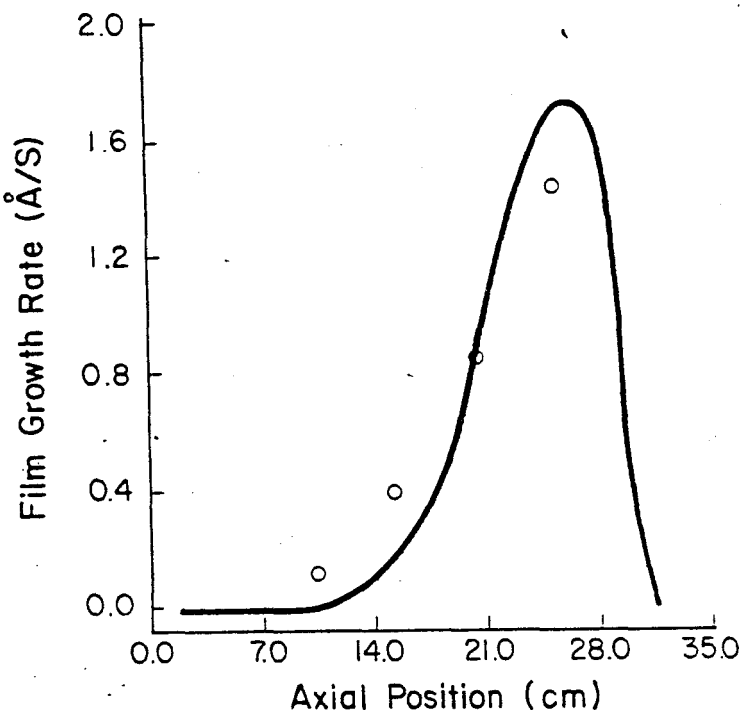


Figure 21a - Film Growth Rate for CVD 244 (400°C, 24 torr, 26.8 s gas holding time; 0 = measured,—= calculated)

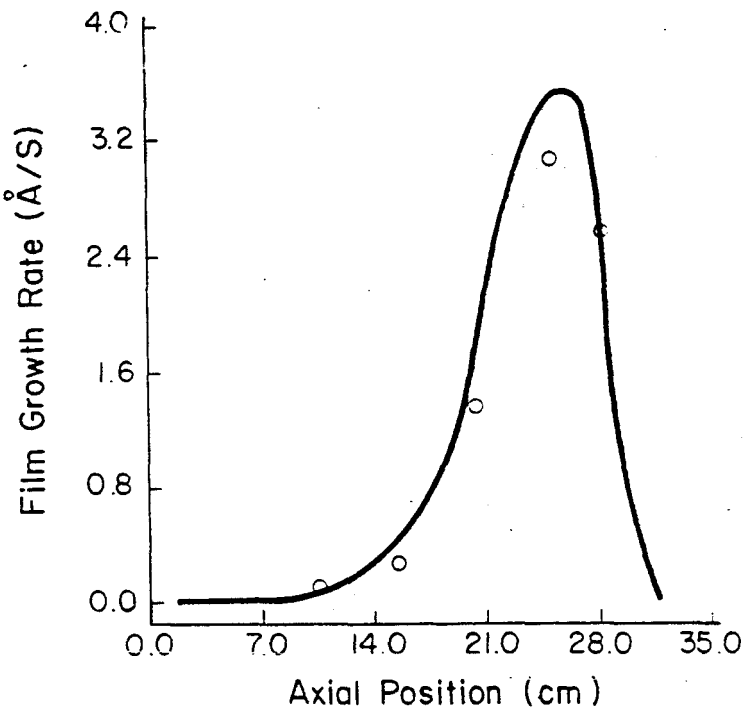


Figure 21b - Film Growth Rate for CVD 256 (400°C, 48 torr, 27 s gas holding time; 0= measured, —=calculated)

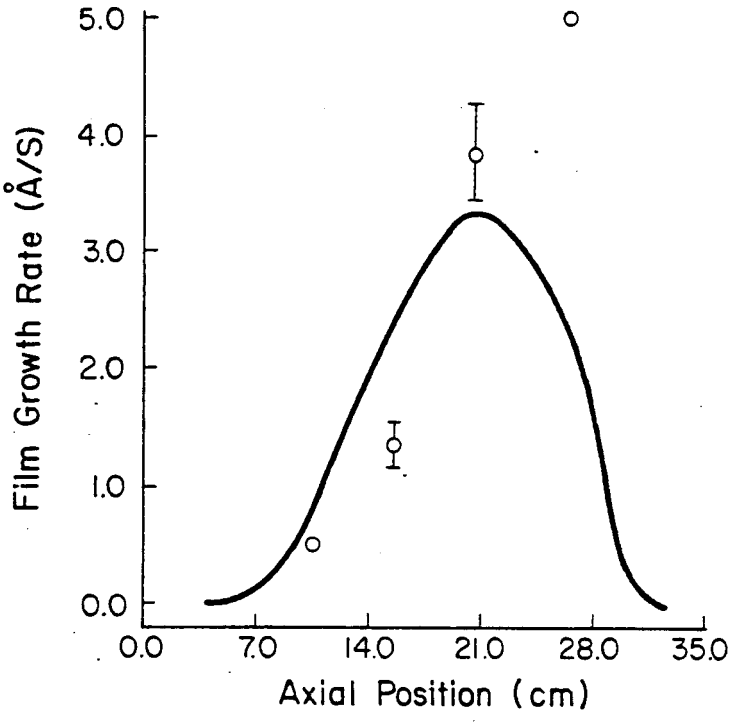


Figure 22a - Film Growth Rate for CVD 92 (420°C, 24 torr, 31 s gas holding time; 0= measured, — = calculated)

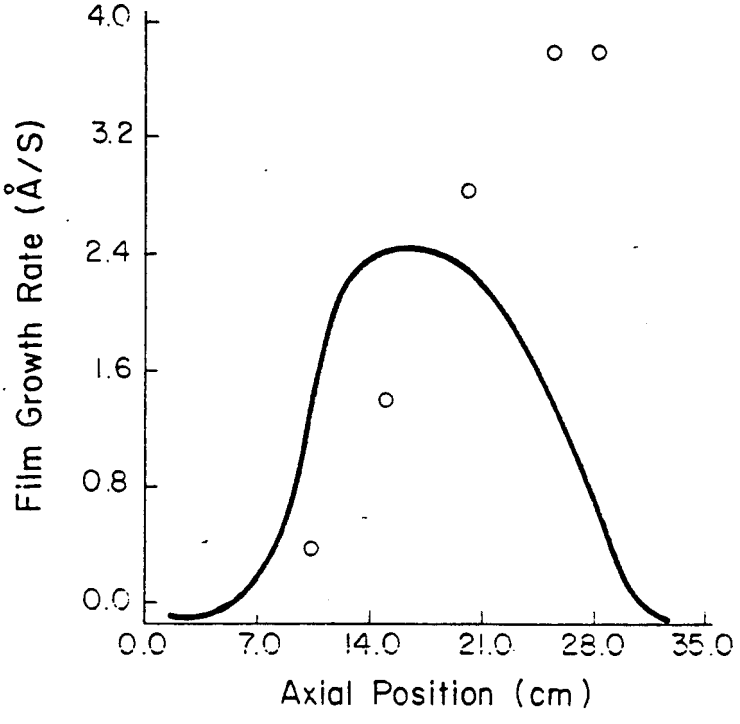


Figure 22b - Film Growth Rate for CVD 96 (420°C, 24 torr, 51s gas holding time; o= measured, — = calculated)

PLANS

During the second half of the contract year, the LPCVD disilane process and cell fabrication procedures will continue to be optimized for high efficiency devices. Alternate sources of disilane, in particular disilane produced by silent electric discharge by Chronar will be evaluated. Boron doped films will be deposited and characterized. Cells with all semiconductor layers formed by CVD will be characterized in both the pin and nip configurations.

CVD intrinsic layers by themselves and in cells will be characterized in greater depth relying on SIMS analysis, analysis of collection efficiency under various bias conditions, surface photovoltage measurement, and measurement of space charge limited current.

Development of the chemical reactor model describing the LPCVD process will continue with emphasis on quantitatively describing the film growth rate, preliminary identification of issues related to raw materials utilization and scale-up, and correlating film quality with reaction conditions.

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APPENDIX 1

Summary of Deposition Conditions and Cell Test History for All Devices

CVD #218 - #222

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 218

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830621	420	24.2	38.0	0.52	
N-LAYER	830621	420	12.3	9.8	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)		GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
218.51	ITO,NIP,MO	5000 TO	4800	4.00 TO 4.17	150	225
218.61	ITO,NIP,MO	5100 TO	4900	4.08 TO 4.25	150	225
218.71	ITO,NIP,MO	4400 TO	4700	3.92 TO 3.67	150	225

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DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 219

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830622	420	24.3	38.2	0.52	
N-LAYER	830622	420	12.2	9.7	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)		GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
219.51	ITO,NIP,MO	2600 TO	2400	3.64 TO 3.94	150	225
219.61	ITO,NIP,MO	2800 TO	2700	4.09 TO 4.24	150	225
219.71	ITO,NIP,MO	2800 TO	2700	4.09 TO 4.24	150	225

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 220

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830623	420	24.2	38.0	0.52	
N-LAYER	830623	420	12.4	9.9	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE.(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
220.71	ITO,NIP,MO	3275 TO 3075	4.66 TO 4.96	100	225

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DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 221

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830627	401	24.3	24.5	0.83	
N-LAYER	830627	419	12.3	9.8	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE.(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
221.51	ITO,NIP,MO	2275 TO 1525	.56 TO .84	100	225
221.61	ITO,NIP,MO	3075 TO 2425	.90 TO 1.14	100	225
221.71	ITO,NIP,MO	3725 TO 3325	1.23 TO 1.38	100	225

DEPOSITION CONDITIONS AND FILM GROWTH FOR CVD 222

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830628	439	24.3	38.6	0.50	
N-LAYER	830628	421	12.2	9.7	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
222.51	ITO,NIP,MO	3875 TO 3125	5.21 TO 6.46	100	225
222.61	ITO,NIP,MO	2825 TO 2675	4.46 TO 4.71	100	225
222.71	ITO,NIP,MO	2075 TO 2075	3.46 TO 3.46	100	225

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CVD Devices #218-222
Cell Test History

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD218.51 Cell # 1			
24-Jun-83	.4589	4.12	35.26	0.76		
			Piece # CVD218.51 Cell # 2			
24-Jun-83	.4754	4.12	37.11	0.83		
			Piece # CVD218.51 Cell # 3			
24-Jun-83	.4782	3.88	37.15	0.79		
			Piece # CVD218.51 Cell # 4			
24-Jun-83	.0413	3.74	25.30			Shorted
			Piece # CVD218.61 Cell # 1			
23-Jun-83	.4868	3.47	39.06	0.75		
24-Jun-83	.4727	3.42	37.64	0.70		
			Piece # CVD218.61 Cell # 2			
23-Jun-83	.4698	3.61	36.82	0.71		
24-Jun-83	.0703	3.24				Uns. I-V
			Piece # CVD218.61 Cell # 3			
23-Jun-83	.4937	3.42	38.77	0.75		
24-Jun-83	.1452	3.30		0.14		Uns. I-V

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD218.61 Cell # 4			
23-Jun-83	.4920	3.42	39.04	0.75		
24-Jun-83	.3952	3.38	31.11	0.48		
			Piece # CVD219.51 Cell # 1			
24-Jun-83	.4521	4.24	35.41	0.78		
			Piece # CVD219.51 Cell # 2			
24-Jun-83	.4590	4.63	35.76	0.87		
			Piece # CVD219.51 Cell # 3			
24-Jun-83	.4642	4.83	35.83	0.92		
			Piece # CVD219.51 Cell # 4			
24-Jun-83	.4785	5.08	36.39	1.01		
			Piece # CVD219.61 Cell # 1			
24-Jun-83	.4751	4.90	36.29	0.97		
			Piece # CVD219.61 Cell # 2			
24-Jun-83	.4654	4.59	36.50	0.89		
			Piece # CVD219.61 Cell # 3			
24-Jun-83	.4625	4.50	36.18	0.86		
			Piece # CVD219.61 Cell # 4			
24-Jun-83	.4644	4.79	36.15	0.92		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD219.71 Cell # 1			
28-Jun-83	.1126	3.59	25.53	0.12		Shorted
			Piece # CVD219.71 Cell # 2			
28-Jun-83	.4673	4.04	29.94	0.65		
			Piece # CVD219.71 Cell # 3			
28-Jun-83	.4582	4.10	29.45	0.63		
			Piece # CVD219.71 Cell # 4			
28-Jun-83	.4681	4.13	31.16	0.69		
			Piece # CVD220.71 Cell # 1			
28-Jun-83	.4784	4.04	30.13	0.67		
			Piece # CVD220.71 Cell # 2			
28-Jun-83	.4749	4.18	31.19	0.71		
			Piece # CVD220.71 Cell # 3			
28-Jun-83	.4863	4.19	31.01	0.72		
			Piece # CVD220.71 Cell # 4			
28-Jun-83	.4867	4.45	31.53	0.78		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD221.5 Cell # 1			
30-Jun-83	.5023	6.29	36.99	1.34		
6-Jul-83	.4949	6.19	36.94	1.29		
4-Aug-83	.4983	5.75	36.68	1.20	695/25/Air	
4-Aug-83	.5055	5.80	36.66	1.23	1/180/H_2	
			Piece # CVD221.5 Cell # 2			
30-Jun-83	.2400	6.43	27.23	0.48		Shorted
6-Jul-83	.1874	5.65	25.93	0.31		Shorted
4-Aug-83	.2551	6.30	27.24	0.50	695/25/Air	Uns. I-V
4-Aug-83	.3140	5.91	29.30	0.62	1/180/H_2	Uns. I-V
			Piece # CVD221.5 Cell # 3			
30-Jun-83	.4836	6.57	35.50	1.29		
6-Jul-83	.0255	7.65				Shorted
4-Aug-83	.0531	5.39			695/25/Air	Shorted
4-Aug-83	.1237	6.24	25.67	0.23	1/180/H_2	Uns. I-V
			Piece # CVD221.5 Cell # 4			
30-Jun-83	.4944	6.77	35.87	1.37		
6-Jul-83	.4884	6.70	35.77	1.34		
4-Aug-83	.4857	5.90	35.48	1.16	695/25/Air	
4-Aug-83	.4974	6.02	35.91	1.23	1/180/H_2	
			Piece # CVD221.6 Cell # 1			
15-Jul-83	.4456	4.60	30.66	0.72		
25-Jul-83	.5059	4.94	33.52	0.96	234/25/Air	
			Piece # CVD221.6 Cell # 2			
15-Jul-83	.4374	4.47	29.17	0.65		
25-Jul-83	.4952	4.70	32.65	0.87	234/25/Air	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD221.6 Cell # 3			
15-Jul-83	.4421	4.50	28.51	0.65		
25-Jul-83	.4735	4.54	31.99	0.79	234/25/Air	
			Piece # CVD221.6 Cell # 4			
15-Jul-83	.4516	4.79	28.64	0.71		
25-Jul-83	.4980	4.50	32.39	0.83	234/25/Air	
			Piece # CVD221.7 Cell # 1			
8-Jul-83	.4891	3.93	33.84	0.74		
			Piece # CVD221.7 Cell # 2			
8-Jul-83	.4877	4.17	33.62	0.78		
			Piece # CVD221.7 Cell # 3			
8-Jul-83	.4897	4.44	33.29	0.83		
			Piece # CVD221.7 Cell # 4			
8-Jul-83	.4985	4.57	31.92	0.83		
			Piece # CVD222.5 Cell # 1			
30-Jun-83	.3844	3.26	35.68	0.51		
4-Aug-83	.3873	3.08	35.00	0.48	840/25/Air	
4-Aug-83	.4049	3.35	35.94	0.56	1/180/H_2	
			Piece # CVD222.5 Cell # 2			
30-Jun-83	.3737	3.14	35.08	0.47		
4-Aug-83	.3750	3.00	34.81	0.45	840/25/Air	
4-Aug-83	.3907	3.24	35.44	0.51	1/180/H_2	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD222.5 Cell # 3			
30-Jun-83	.3669	3.08	35.14	0.45		
4-Aug-83	.3688	2.94	34.47	0.43	840/25/Air	
4-Aug-83	.3801	3.11	35.26	0.48	1/180/H_2	
			Piece # CVD222.5 Cell # 4			
30-Jun-83	.0365	2.95				Shorted
4-Aug-83	.0358	3.48	25.05		840/25/Air	Shorted
4-Aug-83	.0284	4.48	25.08		1/180/H_2	Shorted
			Piece # CVD222.6 Cell # 1			
15-Jul-83	.4179	2.50	35.73	0.43		
			Piece # CVD222.6 Cell # 2			
15-Jul-83	.3923	2.39	34.60	0.37		
			Piece # CVD222.6 Cell # 3			
15-Jul-83	.3893	2.38	34.54	0.37		
			Piece # CVD222.6 Cell # 4			
15-Jul-83	.3979	2.47	34.11	0.38		
			Piece # CVD222.7 Cell # 1			
8-Jul-83	.4112	2.65	35.57	0.44		
			Piece # CVD222.7 Cell # 2			
8-Jul-83	.4050	2.56	34.89	0.41		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD222.7 Cell # 3			
8-Jul-83	.4031	2.52	34.81	0.40		
			Piece # CVD222.7 Cell # 4			
8-Jul-83	.4113	2.57	34.82	0.42		

APPENDIX 2

Summary of Deposition Conditions and Cell Test History for All Devices

CVD #230-#235

DEPOSITION CONDITIONS AND FILM GROWTH FOR CVD 230

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830715	400	24.3	24.5	0.83	
N-LAYER	830715	419	12.5	10.0	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
230.41	ITO,NIP,MO	1420 TO 1060	.39 TO .53	100	225
230.51	ITO,NIP,MO	2550 TO 1800	.67 TO .94	100	225
230.71	ITO,NIP,MO	5930 TO 4500	1.67 TO 2.20	100	225

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DEPOSITION CONDITIONS AND FILM GROWTH FOR CVD 231

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830715	390	24.1	39.3	0.52	
N-LAYER	830715	419	12.5	10.0	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
231.41	ITO,NIP,MO	1000 TO 730	.27 TO .37	100	225
231.51	ITO,NIP,MO	1600 TO 1300	.48 TO .59	100	225
231.61	ITO,NIP,MO	2260 TO 1940	.72 TO .84	100	225
231.71	ITO,NIP,MO	2700 TO 2300	.83 TO 1.00	100	225

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 232

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830718	399	24.2	24.4	0.83	
N-LAYER	830718	419	12.3	9.8	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
232.41	ITO,NIP,MO	1280 TO 950	.35 TO .47	100	450
232.51	ITO,NIP,MO	2000 TO 1550	.57 TO .74	100	450
232.71	ITO,NIP,MO	3700 TO 3100	1.15 TO 1.37	100	450

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DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 233

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830718	390	24.1	39.3	0.52	
N-LAYER	830718	419	12.2	10.2	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
233.41	ITO,NIP,MO	1150 TO 860	.32 TO .43	100	450
233.51	ITO,NIP,MO	2570 TO 2130	.80 TO .95	100	450
233.71	ITO,NIP,MO	3630 TO 3000	1.11 TO 1.34	100	450

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 234

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830719	400	24.2	24.4	0.83	
N-LAYER	830719	419	12.3	9.8	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
234.41	ITO,NIP,MO	1550 TO 1140	.42 TO .57	100	900
234.51	ITO,NIP,MO	0 TO 0	.00 TO .00	100	900
234.61	ITO,NIP,MO	3800 TO 2940	1.09 TO 1.41	100	900
234.71	ITO,NIP,MO	5430 TO 4420	1.64 TO 2.09	100	900

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DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 235

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	830719	390	24.1	39.3	0.52	
N-LAYER	830719	419	12.3	9.8	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
235.41	ITO,NIP,MO	0 TO 0	.00 TO .00	100	900
235.51	ITO,NIP,MO	1730 TO 1330	.49 TO .64	100	900
235.71	ITO,NIP,MO	3340 TO 2730	1.01 TO 1.24	100	900

CVD Devices #230-235
Cell Test History

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD230.4 Cell # 1			
25-Jul-83	.4518	4.38	37.05	0.84		
5-Aug-83	.4279	4.46	35.13	0.77	260/25/Air	
5-Aug-83	.4663	4.78	38.28	0.98	5/180/H_2	
			Piece # CVD230.4 Cell # 2			
25-Jul-83	.4796	4.37	38.47	0.92		
5-Aug-83	.4779	4.47	38.35	0.94	260/25/Air	
5-Aug-83	.3395	4.75	30.07	0.55	5/180/H_2	Uns. I-V
			Piece # CVD230.4 Cell # 3			
25-Jul-83	.4844	4.44	38.18	0.94		
5-Aug-83	.4809	4.51	38.10	0.95	260/25/Air	
5-Aug-83	.4901	4.75	38.93	1.04	5/180/H_2	
			Piece # CVD230.4 Cell # 4			
25-Jul-83	.4892	4.45	37.90	0.94		
5-Aug-83	.4875	4.46	37.86	0.94	260/25/Air	
5-Aug-83	.4922	4.74	38.60	1.03	5/180/H_2	
			Piece # CVD230.5 Cell # 1			
25-Jul-83	.4827	5.05	35.53	0.99		
5-Aug-83	.4843	5.13	35.45	1.01	261/25/Air	
5-Aug-83	.4916	5.56	36.02	1.13	1/180/Air	
			Piece # CVD230.5 Cell # 2			
25-Jul-83	.4807	5.05	34.51	0.96		
5-Aug-83	.4818	5.06	33.54	0.93	261/25/Air	
5-Aug-83	.4900	5.59	35.00	1.10	1/180/Air	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD230.5 Cell # 3			
25-Jul-83	.4809	5.02	33.76	0.93		
5-Aug-83	.4794	5.12	33.85	0.95	261/25/Air	
5-Aug-83	.4898	5.57	34.46	1.07	1/180/Air	
			Piece # CVD230.5 Cell # 4			
25-Jul-83	.4836	5.14	33.68	0.96		
5-Aug-83	.4811	5.16	33.78	0.96	261/25/Air	
5-Aug-83	.4935	5.61	34.15	1.08	1/180/Air	
			Piece # CVD230.7 Cell # 1			
25-Jul-83	.4631	2.99	31.48	0.50		
			Piece # CVD230.7 Cell # 2			
25-Jul-83	.4490	2.53	31.19	0.40		
			Piece # CVD230.7 Cell # 3			
25-Jul-83	.4465	2.28	31.18	0.36		
			Piece # CVD230.7 Cell # 4			
25-Jul-83	.4466	2.10	31.49	0.34		
			Piece # CVD231.4 Cell # 1			
27-Jul-83	.4519	3.65	40.79	0.77		
5-Aug-83	.4559	3.63	41.56	0.79	211/25/Air	
5-Aug-83	.4561	3.75	42.52	0.83	5/180/H_2	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD231.4 Cell # 2			
27-Jul-83	.4627	3.72	41.63	0.82		
5-Aug-83	.4638	3.72	41.57	0.82	211/25/Air	
5-Aug-83	.4611	3.84	41.99	0.85	5/180/H_2	
			Piece # CVD231.4 Cell # 3			
27-Jul-83	.4726	3.79	41.20	0.84		
5-Aug-83	.4711	3.80	40.90	0.84	211/25/Air	
5-Aug-83	.4718	3.90	41.38	0.87	5/180/H_2	
			Piece # CVD231.4 Cell # 4			
27-Jul-83	.4835	3.93	40.94	0.89		
5-Aug-83	.4810	3.95	41.00	0.89	211/25/Air	
5-Aug-83	.4848	4.06	41.22	0.93	5/180/H_2	
			Piece # CVD231.5 Cell # 1			
27-Jul-83		2.60	25.13			Shorted
28-Jul-83		2.76	27.87		1/180/H_2	Shorted
			Piece # CVD231.5 Cell # 2			
27-Jul-83	.5091	4.21	39.51	0.97		
28-Jul-83	.5106	4.20	39.54	0.97	1/180/H_2	
			Piece # CVD231.5 Cell # 3			
27-Jul-83	.5117	4.28	39.18	0.98		
28-Jul-83	.5203	4.32	39.34	1.01	1/180/H_2	
			Piece # CVD231.5 Cell # 4			
27-Jul-83	.5290	4.39	39.46	1.05		
28-Jul-83	.2248	4.36	28.01	0.31	1/180/H_2	Uns. I-V

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD231.6 Cell # 1			
3-Aug-83	.5637	4.60	36.36	1.08		
			Piece # CVD231.6 Cell # 2			
3-Aug-83	.0910	4.08	25.38	0.11		Shorted
			Piece # CVD231.6 Cell # 3			
3-Aug-83	.5641	4.65	35.50	1.06		
			Piece # CVD231.6 Cell # 4			
3-Aug-83	.5619	4.77	36.46	1.12		
			Piece # CVD231.7 Cell # 1			
27-Jul-83	.5259	5.35	34.99	1.13		
28-Jul-83	.5370	5.87	35.74	1.29	1/180/Air	
5-Aug-83	.5369	6.11	34.92	1.31	193/25/Air	
5-Aug-83	.5454	6.19	36.98	1.43	5/180/Air	
			Piece # CVD231.7 Cell # 2			
27-Jul-83	.5235	5.06	35.05	1.06		
28-Jul-83	.5327	5.44	35.75	1.18	1/180/Air	
5-Aug-83	.5336	5.60	35.17	1.20	193/25/H_2AR	
5-Aug-83	.5421	5.83	37.22	1.34	5/180/Air	
			Piece # CVD231.7 Cell # 3			
27-Jul-83	.5213	5.03	34.71	1.04		
28-Jul-83	.5341	5.37	35.46	1.16	1/180/Air	
5-Aug-83	.5361	5.54	34.68	1.18	193/25/H_2AR	
5-Aug-83	.5430	5.85	36.85	1.34	5/180/Air	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD231.7 Cell # 4			
27-Jul-83	.5306	5.00	34.92	1.06		
28-Jul-83	.5426	5.32	35.97	1.19	1/180/Air	
5-Aug-83	.5432	5.44	35.46	1.20	193/25/H_2AR	
5-Aug-83	.5513	5.84	37.36	1.38	5/180/Air	
			Piece # CVD232.4 Cell # 1			
26-Jul-83	.4923	4.55	37.78	0.97		
28-Jul-83	.4899	4.76	37.60	1.00	1/180/H_2	
			Piece # CVD232.4 Cell # 2			
26-Jul-83	.5000	4.91	38.17	1.07		
28-Jul-83	.5049	5.04	38.46	1.12	1/180/H_2	
			Piece # CVD232.4 Cell # 3			
26-Jul-83	.5085	5.08	37.91	1.12		
28-Jul-83	.5113	5.20	38.37	1.17	1/180/H_2	
			Piece # CVD232.4 Cell # 4			
26-Jul-83	.5116	5.19	37.69	1.14		
28-Jul-83	.5175	5.30	38.03	1.19	1/180/H_2	
			Piece # CVD232.5 Cell # 1			
26-Jul-83	.5293	5.46	37.78	1.25		
28-Jul-83	.5317	5.64	37.91	1.30	1/180/Air	
5-Aug-83	.5322	5.63	37.88	1.30	193/25/H_2AR	
5-Aug-83	.5374	5.84	38.73	1.39	5/180/Air	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD232.5 Cell # 2			
26-Jul-83	.5324	5.58	37.37	1.27		
28-Jul-83	.5366	5.77	37.45	1.33	1/180/Air	
5-Aug-83	.5351	5.82	37.50	1.33	193/25/H_2AR	
5-Aug-83	.5400	6.10	38.26	1.44	5/180/Air	
			Piece # CVD232.5 Cell # 3			
26-Jul-83	.5355	5.72	37.80	1.32		
28-Jul-83	.5410	5.87	37.96	1.38	1/180/Air	
5-Aug-83	.5393	5.94	37.87	1.39	193/25/H_2AR	
5-Aug-83	.5457	6.22	38.61	1.50	5/180/Air	
			Piece # CVD232.5 Cell # 4			
26-Jul-83	.5440	5.82	38.03	1.38		
28-Jul-83	.5474	5.99	38.27	1.43	1/180/Air	
5-Aug-83	.5448	6.09	38.24	1.45	193/25/H_2AR	
5-Aug-83	.5490	6.37	38.98	1.56	5/180/Air	
			Piece # CVD232.7 Cell # 1			
26-Jul-83	.5345	5.79	34.23	1.21		
28-Jul-83	.5469	6.08	35.55	1.35	1/180/H_2	
1-Aug-83	.5445	6.17	35.25	1.35	98/25/H_2AR	
			Piece # CVD232.7 Cell # 2			
26-Jul-83	.5225	5.46	32.19	1.05		
28-Jul-83	.5365	5.95	34.06	1.24	1/180/H_2	
1-Aug-83	.5375	6.01	34.01	1.26	98/25/H_2AR	
			Piece # CVD232.7 Cell # 3			
26-Jul-83	.5181	5.35	31.96	1.01		
28-Jul-83	.5326	5.87	33.02	1.18	1/180/H_2	
1-Aug-83	.5326	5.93	32.98	1.19	98/25/H_2AR	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD232.7 Cell # 4			
26-Jul-83	.5264	5.47	31.86	1.05		
28-Jul-83	.5373	5.96	32.71	1.20	1/180/H_2	
1-Aug-83	.5361	6.01	32.66	1.20	98/25/H_2AR	
			Piece # CVD233.4 Cell # 1			
26-Jul-83	.1661	3.00	34.66	0.20		
			Piece # CVD233.4 Cell # 2			
26-Jul-83	.1773	3.26	34.44	0.23		
			Piece # CVD233.4 Cell # 3			
26-Jul-83	.0795	3.36	26.02			
			Piece # CVD233.4 Cell # 4			
26-Jul-83	.2002	3.85	34.27	0.30		
			Piece # CVD233.5 Cell # 1			
26-Jul-83	.2584	4.58	31.92	0.43		
5-Aug-83	.2595	4.32	29.60	0.38	237/25/Air	
5-Aug-83	.2630	5.18	34.38	0.53	1/180/H_2	
			Piece # CVD233.5 Cell # 2			
26-Jul-83	.2578	4.75	33.09	0.46		
5-Aug-83	.2590	4.88	32.75	0.47	237/25/Air	
5-Aug-83	.2636	5.14	34.53	0.54	1/180/H_2	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD233.5 Cell # 3			
26-Jul-83	.2584	4.62	32.56	0.44		
5-Aug-83	.2599	4.66	31.97	0.44	237/25/Air	
5-Aug-83	.2660	5.08	34.02	0.53	1/180/H_2	
			Piece # CVD233.5 Cell # 4			
26-Jul-83	.2614	4.56	32.31	0.44		
5-Aug-83	.2273	4.65	30.92	0.37	237/25/Air	
5-Aug-83		3.98			1/180/H_2	Shorted
			Piece # CVD233.7 Cell # 1			
26-Jul-83	.2606	4.39	30.17	0.39		
			Piece # CVD233.7 Cell # 2			
26-Jul-83	.2521	4.03	29.24	0.34		
			Piece # CVD233.7 Cell # 3			
26-Jul-83	.2485	3.69	28.43	0.30		
			Piece # CVD233.7 Cell # 4			
26-Jul-83	.2496	3.66	28.40	0.30		
			Piece # CVD234.5 Cell # 1			
25-Jul-83	.4850	9.74	31.28	1.69		
			Piece # CVD234.5 Cell # 2			
25-Jul-83	.5424	6.13	35.51	1.35		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD234.5 Cell # 3			
25-Jul-83	.5662	5.44	36.94	1.30		
			Piece # CVD234.5 Cell # 4			
25-Jul-83	.5781	4.76	38.39	1.21		
			Piece # CVD234.6 Cell # 1			
3-Aug-83	.6225	4.74	37.30	1.26		
			Piece # CVD234.6 Cell # 2			
3-Aug-83	.6202	4.74	34.75	1.17		
			Piece # CVD234.6 Cell # 3			
3-Aug-83	.6235	4.76	33.70	1.14		
			Piece # CVD234.6 Cell # 4			
3-Aug-83	.6255	4.87	34.02	1.18		
			Piece # CVD234.7 Cell # 1			
25-Jul-83	.5567	4.79	29.67	0.90		
			Piece # CVD234.7 Cell # 2			
25-Jul-83	.4584	3.84	28.07	0.57		
			Piece # CVD234.7 Cell # 3			
25-Jul-83	.5426	3.39	29.37	0.62		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD234.7 Cell # 4			
25-Jul-83	.5367	3.13	29.17	0.56		
			Piece # CVD235.4 Cell # 1			
27-Jul-83	.4851	3.63	43.34	0.87		
			Piece # CVD235.4 Cell # 2			
27-Jul-83	.4871	3.61	42.87	0.86		
			Piece # CVD235.4 Cell # 3			
27-Jul-83	.4964	3.65	42.09	0.87		
			Piece # CVD235.4 Cell # 4			
27-Jul-83	.5112	3.75	42.40	0.93		
			Piece # CVD235.5 Cell # 1			
27-Jul-83	.5445	4.16	41.80	1.08		
5-Aug-83	.5451	4.19	41.65	1.09	213/25/Air	
5-Aug-83	.5333	4.33	42.03	1.11	1/180/H_2	
			Piece # CVD235.5 Cell # 2			
27-Jul-83	.5476	4.25	41.21	1.10		
5-Aug-83	.5274	4.31	39.45	1.02	213/25/Air	
5-Aug-83	.5405	4.44	41.06	1.13	1/180/H_2	
			Piece # CVD235.5 Cell # 3			
27-Jul-83	.5531	4.34	40.82	1.12		
5-Aug-83	.5451	4.46	40.53	1.13	213/25/Air	
5-Aug-83	.5487	4.58	41.03	1.18	1/180/H_2	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD235.5 Cell # 4			
27-Jul-83	.5589	4.54	40.71	1.18		
5-Aug-83	.5568	4.65	40.69	1.20	213/25/Air	
5-Aug-83	.5563	4.77	41.30	1.25	1/180/H_2	
			Piece # CVD235.7 Cell # 1			
27-Jul-83	.5440	4.18	37.84	0.98		
5-Aug-83	.5392	4.21	37.79	0.98	211/25/Air	
5-Aug-83	.5592	4.43	39.64	1.12	5/180/H_2	
			Piece # CVD235.7 Cell # 2			
27-Jul-83	.5354	4.23	36.57	0.95		
5-Aug-83	.5334	4.26	36.36	0.94	211/25/Air	
5-Aug-83	.5480	4.52	38.57	1.09	5/180/H_2	
			Piece # CVD235.7 Cell # 3			
27-Jul-83	.5284	4.26	35.21	0.91		
5-Aug-83	.5256	4.26	35.27	0.90	211/25/Air	
5-Aug-83	.5434	4.58	37.42	1.06	5/180/H_2	
			Piece # CVD235.7 Cell # 4			
27-Jul-83	.5256	4.30	34.49	0.89		
5-Aug-83	.5229	4.31	34.46	0.89	211/25/Air	
5-Aug-83	.5376	4.64	36.36	1.04	5/180/H_2	

APPENDIX 3

Summary of Deposition Conditions and Cell Test History for All Devices

CVD #300, #305, and #307

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 300

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	831031	401	24.1	24.3	0.83	
N-LAYER	831031	420	12.2	9.7	.35	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
300.41	ITO,PIN,MO	2300 TO 1900	.35 TO .43	300	100
300.42	ITO,PIN,MO	2000 TO 1600	.30 TO .37	300	100
300.51	ITO,PIN,MO	3200 TO 2700	.50 TO .59	300	100
300.52	ITO,PIN,MO	3000 TO 2400	.44 TO .56	300	100
300.61	ITO,PIN,MO	4100 TO 3800	.70 TO .76	300	100
300.62	ITO,PIN,MO	3800 TO 3300	.61 TO .70	300	100
300.71	ITO,PIN,MO	4500 TO 4300	.80 TO .83	300	100
300.72	ITO,PIN,MO	4100 TO 4100	.76 TO .76	300	100

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DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 305

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	831111	420	24.1	23.6	0.83	
N-LAYER	831111	420	12.1	9.6	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)	I-LAYER GR. RATE,(A/S)	N-LAYER THICK.(A)	P-LAYER THICK.(A)
305.41	ITO,PIN,MO	3200 TO 2700	1.80 TO 2.13	300	80
305.42	ITO,PIN,MO	2700 TO 2200	1.47 TO 1.80	300	80
305.51	ITO,PIN,MO	4500 TO 3900	2.60 TO 3.00	300	80
305.52	ITO,PIN,MO	3600 TO 3100	2.07 TO 2.40	300	80
305.61	ITO,PIN,MO	5600 TO 5000	3.33 TO 3.73	300	80
305.62	ITO,PIN,MO	4100 TO 3900	2.60 TO 2.73	300	80
305.71	ITO,PIN,MO	6400 TO 5600	3.73 TO 4.27	300	80
305.72	, IN,MO	0 TO 0	.00 TO .00	300	0

DEPOSITION CONDITIONS AND FILM GROWTH
FOR CVD 307

DEPOSITION CONDITIONS

	DATE	TEMP (C)	PRESS TORR	HOLDING TIME SEC	DIS FLOW CC/MIN	DOP FLOW CC/MIN
I-LAYER	831115	400	24.1	51.7	0.39	
N-LAYER	831115	420	12.1	9.6	.52	.50
P-LAYER	0	0	0.0	0.0	.00	.00

FILM GROWTH

PIECE NO	DEVICE STR	I-LAYER THICK.(A)		I-LAYER GR. RATE,(A/S)		N-LAYER THICK.(A)	P-LAYER THICK.(A)
307.41	ITO,PIN,MO	2400 TO	2000	.51 TO	.62	300	80
307.42	, IN,MO	0 TO	0	.00 TO	.00	300	0
307.51	ITO,PIN,MO	3300 TO	2700	.69 TO	.83	300	80
307.52	, IN,MO	0 TO	0	.00 TO	.00	300	0
307.61	ITO,PIN,MO	3900 TO	3600	.92 TO	1.00	300	80
307.62	, IN,MO	0 TO	0	.00 TO	.00	300	0
307.71	ITO,PIN,MO	4300 TO	4100	1.05 TO	1.10	300	80
307.72	, IN,MO	0 TO	0	.00 TO	.00	300	0

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CVD Devices #300,305,&307
Cell Test History

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD300.41 Cell # 1			
4-Nov-83	.1108	6.34	25.21	0.20		Uns. I-V
			Piece # CVD300.41 Cell # 2			
4-Nov-83	.6888	7.03	48.21	2.67		
			Piece # CVD300.41 Cell # 3			
4-Nov-83	.2052	5.98	25.25	0.35		
			Piece # CVD300.41 Cell # 4			
4-Nov-83	.6890	6.89	46.26	2.51		
			Piece # CVD300.42 Cell # 1			
9-Nov-83	.6626	6.61	48.53	2.43		
			Piece # CVD300.42 Cell # 2			
9-Nov-83	.6682	6.70	48.62	2.49		
			Piece # CVD300.42 Cell # 3			
9-Nov-83	.1190	6.76	25.02	0.23		Uns. I-V
			Piece # CVD300.42 Cell # 4			
9-Nov-83	.5403	6.99	31.37	1.35		Uns. I-V

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD300.51 Cell # 1			
4-Nov-83	.7010	7.40	47.05	2.79		
			Piece # CVD300.51 Cell # 2			
4-Nov-83	.7103	7.26	48.29	2.85		
			Piece # CVD300.51 Cell # 3			
4-Nov-83	.0441	6.40				Shorted
			Piece # CVD300.51 Cell # 4			
4-Nov-83	.7120	7.06	48.24	2.77		
			Piece # CVD300.52 Cell # 1			
9-Nov-83	.7015	7.12	49.86	2.85		
			Piece # CVD300.52 Cell # 2			
9-Nov-83	.7070	7.23	50.04	2.92		
			Piece # CVD300.52 Cell # 3			
9-Nov-83	.7100	7.37	50.13	3.00		
			Piece # CVD300.52 Cell # 4			
9-Nov-83	.6965	7.56	46.13	2.78		
			Piece # CVD300.61 Cell # 1			
4-Nov-83	.7147	7.88	46.18	2.97		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD300.61 Cell # 2			
4-Nov-83	.7124	7.52	45.44	2.78		
			Piece # CVD300.61 Cell # 3			
4-Nov-83	.7098	7.53	45.28	2.76		
			Piece # CVD300.61 Cell # 4			
4-Nov-83	.7100	7.52	44.97	2.75		
			Piece # CVD300.62 Cell # 1			
9-Nov-83	.7102	8.01	49.30	3.20		
			Piece # CVD300.62 Cell # 2			
9-Nov-83	.7129	7.99	49.01	3.19		
			Piece # CVD300.62 Cell # 3			
9-Nov-83	.7101	7.95	48.30	3.12		
			Piece # CVD300.62 Cell # 4			
9-Nov-83	.7070	7.96	47.78	3.08		
			Piece # CVD300.71 Cell # 1			
4-Nov-83	.7189	7.93	45.30	2.95		
			Piece # CVD300.71 Cell # 2			
4-Nov-83	.7162	7.77	44.54	2.83		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD300.71 Cell # 3			
4-Nov-83	.1509	6.65	25.42	0.29		Uns. I-V
			Piece # CVD300.71 Cell # 4			
4-Nov-83	.7162	7.56	42.94	2.66		
			Piece # CVD300.72 Cell # 1			
9-Nov-83	.7209	9.21	48.72	3.70		
17-Nov-83	.7268	9.18	49.39	3.77		
7-Dec-83	.7246	9.62	49.50	3.94	1/175/Air	
			Piece # CVD300.72 Cell # 2			
9-Nov-83	.7209	9.13	47.94	3.61		
17-Nov-83	.7265	9.22	48.55	3.72		
7-Dec-83	.7247	9.65	48.88	3.91	1/175/Air	
			Piece # CVD300.72 Cell # 3			
9-Nov-83	.7183	9.52	47.45	3.71		
17-Nov-83	.7244	9.62	48.02	3.82		
7-Dec-83	.7247	9.98	48.33	4.00	1/175/Air	
			Piece # CVD300.72 Cell # 4			
9-Nov-83	.7157	8.49	46.74	3.25		
17-Nov-83	.7215	8.59	47.33	3.35		
7-Dec-83	.7244	8.90	47.61	3.51	1/175/Air	
			Piece # CVD305.41 Cell # 1			
21-Nov-83	.7271	7.36	48.95	3.00		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD305.41 Cell # 2			
21-Nov-83	.7300	7.32	48.41	2.96		
			Piece # CVD305.41 Cell # 3			
21-Nov-83	.7275	7.37	48.22	2.95		
			Piece # CVD305.41 Cell # 4			
21-Nov-83	.7301	7.56	47.85	3.02		
			Piece # CVD305.42 Cell # 1			
23-Nov-83	.6858	7.14	46.85	2.62		
			Piece # CVD305.42 Cell # 2			
23-Nov-83	.6995	7.22	48.30	2.79		
			Piece # CVD305.42 Cell # 3			
23-Nov-83	.7020	7.26	48.32	2.82		
			Piece # CVD305.42 Cell # 4			
23-Nov-83	.7072	7.31	48.39	2.86		
			Piece # CVD305.51 Cell # 2			
21-Nov-83	.7153	7.74	45.73	2.89		
			Piece # CVD305.51 Cell # 4			
21-Nov-83	.7241	7.58	45.62	2.86		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD305.52 Cell # 1			
23-Nov-83	.7176	7.65	48.22	3.03		
			Piece # CVD305.52 Cell # 2			
23-Nov-83	.6992	7.75	44.26	2.74		
			Piece # CVD305.52 Cell # 3			
23-Nov-83	.7223	7.86	47.58	3.09		
			Piece # CVD305.52 Cell # 4			
23-Nov-83	.7250	7.99	47.39	3.14		
			Piece # CVD305.61 Cell # 1			
21-Nov-83	.7361	7.95	45.45	3.04		
30-Nov-83	.7345	7.63	45.28	2.90	3/25/Air	
			Piece # CVD305.61 Cell # 2			
21-Nov-83	.7334	8.10	44.83	3.04		
30-Nov-83	.7345	7.76	44.80	2.92	3/25/Air	
			Piece # CVD305.61 Cell # 3			
21-Nov-83	.7360	8.14	44.53	3.05		
			Piece # CVD305.61 Cell # 4			
21-Nov-83	.7332	8.33	44.40	3.10		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD305.62 Cell # 1			
23-Nov-83	.7250	7.50	46.79	2.91		
			Piece # CVD305.62 Cell # 2			
23-Nov-83	.7278	7.35	46.37	2.84		
			Piece # CVD305.62 Cell # 3			
23-Nov-83	.7302	7.30	46.27	2.82		
			Piece # CVD305.62 Cell # 4			
23-Nov-83	.7307	7.27	46.82	2.84		
			Piece # CVD305.71 Cell # 1			
21-Nov-83	.7275	7.48	44.23	2.75		
			Piece # CVD305.71 Cell # 2			
21-Nov-83	.7302	7.47	43.65	2.72		
			Piece # CVD305.71 Cell # 3			
21-Nov-83	.7333	7.58	43.40	2.76		
			Piece # CVD305.71 Cell # 4			
21-Nov-83	.2026	7.39	25.82	0.44		Uns. I-V
			Piece # CVD307.41 Cell # 1			
21-Nov-83	.7169	7.52	50.14	3.09		

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD307.41 Cell # 2			
21-Nov-83	.7193	7.53	49.88	3.09		
			Piece # CVD307.41 Cell # 3			
21-Nov-83	.5158	7.56	30.04	1.34		Uns. I-V
			Piece # CVD307.41 Cell # 4			
21-Nov-83	.7222	7.65	49.20	3.11		
			Piece # CVD307.51 Cell # 1			
21-Nov-83	.7113	7.61	48.37	2.99		
30-Nov-83	.7080	7.29	47.65	2.81	3/25/Air	
7-Dec-83	.7057	7.89	48.91	3.11	1/175/Air	
			Piece # CVD307.51 Cell # 2			
21-Nov-83	.0137	6.77	25.16			Shorted
30-Nov-83	.0130	6.25	25.28		3/25/Air	Shorted
7-Dec-83	.0166	6.82	25.02		1/175/Air	Shorted
			Piece # CVD307.51 Cell # 3			
21-Nov-83	.7276	7.90	48.56	3.19		
30-Nov-83	.7266	7.52	48.36	3.02	3/25/Air	
7-Dec-83	.7292	8.11	48.74	3.30	1/175/Air	
			Piece # CVD307.51 Cell # 4			
21-Nov-83	.7294	7.95	48.33	3.20		
30-Nov-83	.7233	7.47	47.54	2.94	3/25/Air	
7-Dec-83	.7313	8.17	48.52	3.31	1/175/Air	

Test Date	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)	HeatTreat. Hr/Deg/Atm	Test Comm
			Piece # CVD307.61 Cell # 1			
21-Nov-83	.7315	7.87	48.34	3.18		
			Piece # CVD307.61 Cell # 2			
21-Nov-83	.7340	7.93	47.99	3.19		
			Piece # CVD307.61 Cell # 3			
21-Nov-83	.7365	7.97	47.67	3.20		
			Piece # CVD307.61 Cell # 4			
21-Nov-83	.7366	8.02	47.75	3.23		
			Piece # CVD307.71 Cell # 1			
21-Nov-83	.7363	8.02	47.05	3.18		
30-Nov-83	.7367	7.75	48.11	3.14	15/180/Air	
			Piece # CVD307.71 Cell # 2			
21-Nov-83	.7343	7.83	46.59	3.06		
30-Nov-83	.7372	7.60	48.08	3.08	15/180/Air	
			Piece # CVD307.71 Cell # 3			
21-Nov-83	.7365	7.72	46.11	3.00		
30-Nov-83	.7399	7.50	47.91	3.04	15/180/Air	
			Piece # CVD307.71 Cell # 4			
21-Nov-83	.7366	7.78	46.22	3.03		
30-Nov-83	.7422	7.56	47.56	3.05	15/180/Air	